THE RELATION OF SUBSURFACE TILLAGE TO SOIL MOISTURE, NITRIFICATION, AND SOIL AGGREGATION, AND THE RELATION OF MICROORGANIC POPULATION TO SOIL AGGREGATION

by

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INTRODUCTION

Conditions of drought through the Central West in the Nineteen Thirties emphasized the need for conservation of soil moisture. When rainfall is low and evaporation is high, such conservation may mean the difference between success or failure of a crop. Thompson (1936), working in South Africa under conditions comparable with those at Manhattan, estimated that corn transpires about 50 percent of the rainfall while about 35 percent of the rainfall is lost through evaporation and about 15 percent through runoff. Salmon and Throckmorton (1929) pointed out the necessity of moisture conservation in central and western Kansas and the need of cultural methods which would accomplish this. Many attempts have been made to conserve much of that rainfall which reaches the surface of the soil and at the same time to reduce erosion. Through the use of contour farming, strip cropping, terracing, etc., this has been partially accomplished.

Loss of water through runoff under conditions of cultivation is almost universally accompanied by loss of soil and associated soil nutrients in either suspension or solution. Bennett and Lowdermilk (1938) have reviewed the soil erosion problem extensively. They presented evidence to show that erosion has entered every major agricultural region of the United States, and therefore to some degree erosion has influenced the production of every staple commodity. They state that 43 percent of the crop lands of the United States are now in need of erosion-control practices. It is fortunate that moisture conservation and erosion control are so intimately related, for those factors which accomplish the one, tend to control the other.

At times, such as the period 1930-1936, wind is a very important erosion factor; hence an attempt has been made to develop cultural practices which will control the effect of both elements and at the same time conserve soil moisture.

Stubble, which often has been left on the surface of fields, conserves moisture and prevents erosion. Frequently in the Great Plains the only cultivation such fields receive is a disking at seeding time or no other cultivation than such as might be accomplished by "stubbling in" of the seed.

Of more recent vintage is the practice of stubble-mulch tillage. By allowing crop residues to remain on the surface, Duley and Kelly (1939), and Beutner and Anderson (1943), have been able to show that soil moisture was increased while runoff and erosion were greatly reduced. There can be little doubt that the practice of returning crop residues is desirable, but when this is combined with subsurface tillage, many questions may be raised. Among these questions are the effect of the treatment on yield, nitrate accumulation, soil structure, bacterial population, and organic matter depletion.

It was in an attempt to answer some of these questions that this study of subsurface tillage was undertaken. It is realized that in such a brief period as the two years of study, many long-time trends may not be apparent. However, certain trends and observations are indicative of future expectations and have been presented in the hope that they will bring about a better understanding of some of the soil processes connected with subsurface cultivation.

REVIEW OF LITERATURE

Moisture Accumulation and Erosion Control

Many workers have investigated the relation of plant residue management to soil moisture accumulation and erosion. In general, residue management increases soil moisture and decreases soil loss through erosion.

Lowdermilk (1930) has shown that when forest litter is used as a surface cover, runoff is greatly reduced, especially in fine-textured soils. His conclusion is that the suspended particles in runoff water from bare soils filter out at the surface and seal the pores sufficiently to account for the marked difference in the rate of absorption between bare and litter-covered soils. It was further noted that the capacity of forest litter to absorb rainfall was insignificant in comparison with its ability to maintain a high percolation rate in the soil profile.

In working with pastures, Beutner and Anderson (1943) were able to show a decrease in the percentage of water loss from 61.9 for bare soils to 19.5 for grass covered with straw mulch.

Feustel and Byers (1936) have shown that increasing the moisture-holding capacity of the soil through the addition of organic matter does not necessarily increase the amount of available water and may be harmful in that it increases the evaporation rate.

Duley and Miller (1923) determined runoff and erosion over a 6-year period on plots under different types of cultivation. They were able to show that plots in sod absorbed the most water followed by plots in a rotation of corn, wheat, and clover. Plots which were not cultivated but had the weeds

removed, absorbed the least amount of water. From the erosion standpoint, plots plowed 4 inches deep and fallowed, showed greatest soil loss, while sod cover protected the soil to the greatest extent. They concluded that the use of a rotation including grass or clover was best for erosion control.

In working with mulched and unmulched plots, Duley and Kelly (1939) concluded that the degree of slope had but slight effect on the rate of infiltration on mulched plots. After runoff began, there was little change in the rate of infiltration with increased rate of water application. Straw mulch increased the total intake of water and the rate of infiltration over that of bare surface. Conditions of the surface were shown to be the principal factor influencing infiltration and runoff. The formation of a layer at the surface quite impervious to water was prevented by straw covering. When the surface was left bare, soil type and structure had little effect on infiltration.

Through the medium of field and lysimeter tests, Lamb and Chapman (1943) showed that in some cases evaporation was slightly higher under such covers as straw mulch or 65 percent flagstone than under clean cultivation. Straw mulch was also found to decrease the soil temperature by as much as 20 degrees F. as compared with a stone cover of 18 percent.

From field measurements, Duley and Russel (1943) concluded that even small amounts of crop residue greatly reduced runoff and erosion, the reduction in erosion being relatively greater than that of runoff. They suggest the proper use of contour farming, crop sequence, and surface residue to control erosion.

Salmon and Throckmorton (1929) pointed out that top dressings of 3000 pounds per acre of straw tended to retard spring growth and reduce yields.

For the 10-year period, 1911-1920, the yields from plots double-disked at seeding time only were about 1/3 of those from plots which were plowed deep in July. These workers also pointed out the difficulty encountered in the control of Hessian fly where excess volunteer was experienced.

Of 7 cultural treatments, Duley and Russel (1939) found 2 tons of straw on the surface to conserve the greatest percentage of rainfall and to allow the deepest penetration of moisture. Eight tons of straw per acre applied to the surface resulted in the highest yield of air-dried corn fodder and the highest storage of soil moisture. Admitting that some effects of surface mulch may be adverse, they suggest its use primarily for conservation of soil and water.

The rainfall characteristics most important in erosion are intensity, duration, and frequency, as shown by Blumenstock (1939). He further states:

> Protracted periods without precipitation make the soil particularly susceptible to removal by rainwater and wind. It is clear, therefore, that rainless intervals of long extent engender erosion. . . During droughts the physical properties of the soil are modified by excessive drying, its power of cohesion is lessened, and it becomes more susceptible to the forces of wind and water.

The amount of moisture conserved in the soil will not only depend upon that retained where it falls, but will also depend upon evaporation.

Baver (1936), in a review of literature on moisture movement, cites the contention of Veihmeyer that losses of soil moisture by evaporation are largely confined to the upper 8 inches and that the greatest loss occurs from the upper 4. He further points out the higher infiltration rate which accompanies increased non-capillary pore space.

State of Aggregation

The non-capillary pore space is a function of the state of aggregation of the soil. When the soil is well aggregated, the pore space designated as

non-capillary is increased and the soil air-soil water relationship with the plant root is generally considered to be improved.

Cole (1939) using a dry method of screening for aggregate separation, pointed out that cultivation increases the percentage of small aggregates at the expense of the larger aggregates. In the more moist plots there was a greater percentage of aggregates in the size range 3/128 inch to 3/4 inch and a smaller percentage of aggregates both larger and smaller than this size. Highly pulverized soils showed increased cloddiness following irrigation.

Martin (1943) concluded that composts and compost material added to soil influenced the state of aggregation. In general, the higher the percent of readily decomposable constituents in the organic material, the greater was its influence upon aggregation. This was attributed to microorganisms. He found that the effect from highly composted material was less than that from material which had undergone a smaller degree of decomposition. Relatively inactive materials as peat plus timothy hay had little influence on the state of aggregation.

In studies on the effect of incorporated sucrose, alfalfa, rye plus vetch, and wheat straw, with Gilpin silty clay loam, Browning and Milan (1941) concluded that all treatments up to applications of 8 tons per acre increased the state of aggregation of those fractions larger than 0.25 mm. These increases were significant for each unit increase in organic matter. Sucrose was the most effective and wheat straw the least effective in producing aggregation.

Baver and Rhoades (1932) have pointed out that soils high in organic matter contain 20 to 30 percent more aggregates than soils which are low in this material. They further state that aggregates high in organic matter

may be as much as 3 times more stable than those low in organic matter.

Browning (1937) pointed out that organic matter added to the soil decreased the dispersion of the soil material which was less than 50 microns in size. He used chopped alfalfa at 6 and 12 tons per acre, and determined their effect after 1, 3, and 5 months. In general, the effect of added organic matter was noticeable within 1 month through increased infiltration and percolation rates. He concluded that the effect of moisture content on the rate of dispersion was dependent upon the amount of colloidal material present. When the soil was rich in organic or inorganic colloid, moisture content had little or no effect on the dispersion rate, but when the colloid fraction was low, dispersion increased with moisture content.

Kolodny and Joffe (1939) designated the fraction less than 40 microns in size as the micro-aggregated fraction and studied the dispersion of this fraction in relation to soil moisture. Their studies led them to conclude that dispersion increases with increased moisture content. They were also able to show that soils which were slowly wet by capillarity were dispersed to a greater extent than the same soil when wet rapidly. They suggested that such studies made on samples from the field gave a better picture of actual soil conditions than was obtained from air-dried samples. However, from a study of dry soil aggregates, Yoder (1936) concluded that rapid wetting of soils resulted in entrapment of air, and the resultant pressure developed broke down the aggregate.

Work with polar liquids has led McHenry and Russell (1943) to believe that hydration associated with polar liquids are the important factors in formation of water-stable aggregates. They related this to hydration of the ions and concluded that drying appears to be one of the most effective agents

for aggregate production. Their work was on artificial soils.

From the results of 4 years of experiments, Alderfer and Merkle (1943) have concluded that surface applications are more effective than incorporation of residues in producing structural stability, in increasing permeability and infiltration, and in maintaining good moisture conditions.

Elson (1943) defined the macroaggregates as those aggregates from 1 to 8 mm. in size and concluded that their occurrence was 8 percent greater under fertilized or manured plots than under untreated plots. Manured plots contained 15 percent more such aggregates than fertilized plots. Manure was found to be more effective in wet years than in dry years in increasing the number of macroaggregates.

In greenhouse experiments, Peele and Beale (1943) noted that the rate of formation of water-stable aggregates was similar to the rate of bacterial growth as shown by carbon dioxide production. A high state of aggregation persisted after microbial activity had declined. Large aggregates were gradually converted into smaller aggregates.

Myers and McCalla (1941) worked with soils to which 1000 p.p.m. sucrose had been added. They found a significant rise in the state of aggregation for all aggregates larger than 0.105 mm. A highly significant correlation coefficient was also found between bacterial numbers and the state of aggregation. This disappeared with time. However, studies on sterilized soils showed that the addition of water to air-dry soil was the primary factor in promoting aggregation and that bacterial numbers probably played a secondary role.

That soil aggregates may have a marked influence upon water movement in the soil was shown by Leamer (1942) who, in a study of the effect of artifi-

cial aggregates on moisture movements, states:

> As long as evaporation does not take place more rapidly than capillary conductivity can replace the water lost from the surface of the soil, the moisture content of the interior of the soil mass will continue to decrease . . . Thus with slow evaporation rates such as are found under some types of mulches or in very humid weather, the moisture content of the soil may be reduced to a rather low level by evaporation directly from the surface. Under conditions favoring rapid evaporation, the rate of liquid movement may be exceeded at a considerably higher moisture content.

This would mean that when evaporation rates are high and the capillary contact is broken, a higher moisture content is maintained than in cases where capillary contact is not broken.

Peterson (1943), after treating samples from the B horizon of certain soils with cornstalks, alfalfa, or sucrose, puddled the soil and subjected it to wetting and drying. Sterilized and unsterilized samples were studied. Aggregates were determined by direct counting methods. In general, if the soils were sterilized, aggregates greater than 0.1 mm. were not changed in number by the addition of 5 tons per acre of cornstalks, alfalfa, or sucrose. With some exceptions, similarly treated soil, when puddled but not sterilized, gave similar results.

Carbon and Nitrogen Content of the Soil

Carbon and nitrogen content of the soil have been shown by many workers to influence the fertility of the soil as well as the state of aggregation.

From the results of 60 years of cultivation in Missouri, Jenny (1933) has shown that there is a 35-percent decrease in total nitrogen and a 38-percent decrease in organic matter on non-errosive soils. He suggests that since the curve of decrease of nitrogen and organic matter tends to level off, levels reached after an initial period of cultivation may be maintained

only by the use of rotation with manure or crop residue.

Baker (1937), in a study of cover crops in orcharding, concluded that rye was the best of 7 crops tried in maintaining total nitrogen content of the soil, but even in this case when all residues were returned, a 20-percent loss in total nitrogen was observed over a 23-year period.

In a study of central and western Kansas soils, Sewell and Gainey (1932) have shown that a marked decrease in the loss of carbon and nitrogen was brought about by the addition of organic matter to the soil. They concluded that such additions may also give protection against blowing, but point out that incorporating of straw should be at such a time that it will be least injurious to the crop. This would be as soon as possible after crop removal.

Metzger (1939) showed that continuous cultivation widens the carbon-nitrogen ratio of soils under certain cropping practices. The surplus of carbon in treated over untreated plots could be accounted for by the return of crop residues to the former. Much or all of the nitrogen surplus could be accounted for in like manner.

Salter and Green (1933) concluded from study of the carbon and nitrogen on plots which had been continuously cropped for 32 years that the crop yield was positively correlated with the carbon and nitrogen content of the soil.

Albrecht (1936) concluded that when red clover was added to surface soil a greater increase in surface nitrogen resulted than when the same was incorporated within the soil. Plowing led to rapid decomposition and the nitrogen was more susceptible to leaching.

Hide and Metzger (1939) pointed out that a poorly aggregated fraction of soil contained less carbon and less nitrogen than a well aggregated fraction. The percentage of carbon was relatively lower than the percentage of nitrogen.

This resulted in a narrower carbon-nitrogen ratio in the poorly aggregated fraction.

A higher content of carbon and nitrogen in the well aggregated fraction than in the poorly aggregated fraction of soils was also demonstrated by Weldon and Hide (1942). They further showed that the sesquioxides of iron and aluminum were present to a far greater extent in the well aggregated fraction than in the poorly aggregated fraction.

A highly significant correlation between the state of aggregation and the amount of carbon and nitrogen in the soil was pointed out by Ackerman and Myers (1943). They concluded that, as far as aggregate formation is concerned, the ratio of carbon to nitrogen is not as important as the total amount of organic carbon present.

Nitrate Accumulation

Nitrate accumulation in the soil is a process relegated primarily to the nitrifying and ammonifying species of soil organisms. Their activity depends, in turn, upon the readily available carbon and nitrogen of the soil. Nitrate accumulation exerts a marked influence upon crop yields, extent of cover, and protein content of cereals. Cultural practices have been so designed as to afford an accumulation of nitrate following the incorporation of residue in the surface soil.

Albrecht and Uhland (1925) demonstrated that straw mulch depressed nitrate accumulation, increased soil moisture, and reduced air space and soil temperature below that of unmulched plowed soil. Mulch brought on changes in soil structure which resulted in less granulation and poorer tilth. Ammonia accumulation was higher under mulched soils.

Gainey (1920) pointed out that over a period of 5 years such practices as disking at seeding time accumulated over 4 times as much organic matter in the 0 to 3-inch layer as accumulated in the corresponding layer in soil which had been deep plowed. When the land was plowed the organic matter was uniformly distributed throughout the plowed layer, but when the soil was disked it was 6 times greater in the surface layer than in the 4 to 7-inch layer. He has shown that the low nitrate accumulation in soils from continuously disked plots was not due to a lack of nitrifying microflora, since under laboratory conditions such soils gained as much, or more, nitrate than similar soils which had been plowed.

Call (1914) presented evidence to show that soil cultivation practices which leave cover or residue on the surface, such as disking, lead to lower nitrate accumulation and lower yields when compared with the practice of plowing. Graphs were also presented which indicate a greater dependence of yield upon nitrate accumulation than upon moisture accumulation.

Lill (1910) has pointed out that the rapidity of production and accumulation of nitrate depend to a large extent on the moisture present. Graphs are presented which show that nitrate formation declines after soil moisture reaches 25 to 30 percent.

Sewell and Gainey (1932) concluded that of 3 methods studied, namely, cultivation—6 inches, cultivation—3 inches, and uncultivated, the first was by far the best as far as nitrate accumulation between harvest and seeding time were concerned.

Salter (1931) has shown that when materials with a wide carbon-nitrogen ratio are added to the soil, no nitrate is released until a ratio of approximately 10-1 is reached. Since straw has a wide carbon-nitrogen ratio, no

nitrate will be released from the organic matter until extensive decomposition has taken place.

Nitrate was found to move freely with moisture movements by Krantz and Searsoth (1943) in their investigations of soils. Droughty conditions resulted in nitrate accumulation near the surface due to upward movement of water.

Scott (1921) has shown that, of several treatments used, surface applications of straw at 4 tons per acre resulted in lowest nitrate content, lowest temperature, and highest moisture content throughout the summer months, but a similar application of 2 tons per acre resulted in fairly large accumulations of nitrates by the end of summer. When the straw was incorporated, 4 tons per acre resulted in decreased nitrate accumulation the following spring, but a total nitrate content equal to the untreated plots was found during the summer. The incorporation of 2 tons of straw did not affect the nitrate accumulation at either season.

Soil Microorganic Population

The role of microorganisms in maintaining or increasing soil fertility has been the subject of extensive research. Little is known about the influence of microorganisms on the development of soil structure.

McCalla and Duley (1943) found that only 50 percent of a 4-ton application of straw had decomposed after a 6-months period in contact with surface soil. They concluded that if nutrients were needed by the crop, they could be made available more rapidly by incorporation of residue. Scott (1921) has shown that nutrients become available if sufficient time is allowed.

In working with various genetic soil types containing different amounts of organic matter, Vandecaveye and Katznelson (1940) concluded that there was no significant relation existing between the total content of humified organic matter in the soil and the microbial numbers supported by it. In general, they found that differences in the composition of humus in the various genetic soil types corresponded broadly to the activity of certain microbial groups. The nature of the humus had more effect on the prevailing species than upon total numbers.

Kanivets and Korneeva (1937) concluded that soils "contaminated" with Azotobacter and Trichoderma had a water resistance 2 to 2.5 times that of soils not containing these organisms. They believed that the biochemical processes resulting from such "contamination" had a favorable effect on the structural strength of the soil.

Martin and Waksman (1940) used artificial soils plus amendments and natural soils plus amendments to study the influence of microorganisms on binding of soil particles. They concluded that binding of the particles depended upon the nature of the microorganism, amount of growth, and nature of the substrate. More thorough binding was observed in cases of more rapid decomposition. In general, the dry soils contained more bound material than did the wet soils. The effects discussed are mainly those produced by fungi and Azotobacter indicum. This latter was noted to produce large amounts of "slimy" material.

Winogradski and Ziemiecka (1927) have reviewed the work of Gainey and again point out that Azotobacter are usually absent in soils with a pH less than 6.0.

Lyon and Buckman (1937) point out that the average pH of a representa-

tive acid mineral soil is about 5.8. Since the pedalfers in general fall into this classification, the influence of Azotobacter in these soils would be negligible.

Peele (1940) used mucilaginous substances produced by microorganisms on artificial media as a binding material to produce artificial aggregates in puddled soils. These aggregates showed high resistance to wetting and extreme stability. When sucrose was used as an amendment in sterile soils and the soils inoculated, a similar binding action was observed. Peele concluded that fungi were more effective than bacteria in aggregate production.

Although it is a well known fact that many species of organisms when grown on artificial media produce large amounts of mucilaginous substances, gums, or "slimy" substances, production of large volumes of this material in the soil is open to question.

In studying the binding effect of organisms on the soil fraction less than 50 microns in diameter, Martin and Waksman (1941) concluded that a higher percentage of such fraction was bound in the presence of casein than in the presence of lignin or in the control. Aspergillus niger in the presence of alfalfa, manure, and peat amendments gave slightly less aggregation than in the presence of casein. They concluded that in the early stages of decomposition, products released, such as gums, exerted the greatest binding effect, but in later stages the greatest binding effect was of a physicochemical nature. Greatest differences in number of particles bound were observed when ground alfalfa was used in the presence of A. niger or a soil suspension.

Kanivets (1939) demonstrated that "contaminating" the soil with Trichoderma lignorem increased the "textural" strength and moisture content and improved nutritional conditions. T. lignorem also exerted a favorable

influence on Azotobacter. Aspergillus niger was shown to intensify the effect when added with T. lignorem.

Using the pipette method for aggregate analysis, Waksman and Martin (1939) pointed out the favorable effect of microorganisms on aggregation of soil particles. Soil infusion, cultures of Aspergillus niger, Trichoderma plus Penicillum, and Bacterium fluorescens were used. Soil infusion exerted the greatest effect, but this was only about two times that of A. niger. Bact. fluorescens had the least effect on binding soil particles.

Kanivets, Korneeva, and Morachkorskii (1940) concluded that the quantity of soil aggregates resistant to water increased if the soil was composted and inoculated with T. lignorem and A. niger.

McCalla (1943) worked with aggregates from soil to which sucrose had been added. He concluded that the increased resistance of the aggregates to wetting and their greatly increased resistance to destruction by falling water drops was primarily due to the presence of fungal mycelia.

That molds had a marked influence on the state of aggregation was shown by Martin and Anderson (1943). They suggested that those molds which developed last in the cycle of decomposition exerted the greatest effect on state of aggregation.

Cultural Practices and Yield

The immediate economic aspect of a process is of primary importance to its practical application. If yields must be sacrificed for soil conservation by any method suggested, it will be difficult to have that recommendation adopted by the person who depends for his livelihood upon crop returns.

Sewell and Call (1925) have presented data to show that yields in the

area of Manhattan are more dependent upon nitrate accumulation at seeding time than upon soil moisture. The treatment, late preparation by disking at seeding time, reduced the yield to about one-fourth of that resulting from deep plowing. They concluded that plowing is necessary for reasons other than weed control. The practice of disking at seeding time as a means of seedbed preparation is quite comparable to subsurface tillage in that much residue is left at the surface.

Working on nitrogen spots in wheat fields, Gainey and Sewell (1932) found that these spots were accompanied by a higher total nitrogen of the soil, higher nitrate content of the soil, higher percentage nitrogen of the growing plant, higher nitrogen absorption by the plant, higher yield of grain and higher protein content of grain.

Browning, Norton, and Shedd (1943) in working with subsurface cultivation concluded that, in general, subsurface cultivators and sweep attachments for listers under the conditions of the experiment were not an entirely satisfactory means of cultivation. They encountered greater difficulty in weed control, unfavorable nutritional conditions during growing seasons, and lower yields.

Three years' study has led Van Doren and Stauffer (1943) to the conclusion that surface mulches decrease runoff and erosion and crop yield, but result in a slight increase in the state of aggregation.

It is quite generally agreed that increased carbon and nitrogen tend to improve soil structure. There is little doubt that the incorporation of crop residues results in increased nitrate content of the soils and that crop yields in this area are dependent to a greater extent upon the nitrate content of the soil at seeding time than upon the moisture content. This does

not necessarily hold for the drier sections of the Middle West. It is also evident from the literature that the effect of soil microorganisms upon the state of aggregation seems to be confined more to the fungi and fungal-like species than to the true bacteria. Most of the studies have been made in the laboratory. Many amendments such as casein and sucrose with applications up to 50 tons per acre cannot feasibly be duplicated in the field. The literature contains little information on the relation of the state of aggregation of field soils to the microbiological population. The short duration of all experiments with subsurface tillage should also be pointed out. Many effects, and especially those associated with the carbon content of the soil, as the state of aggregation, nitrate accumulation, crop yields, etc., cannot be justly evaluated in a period of 3 or 4 years.

DESIGN OF EXPERIMENT

In the summer of 1942, 12 plots were laid out at the Agronomy Farm, Kansas Agricultural Experiment Station, in such a manner that the length of the plot followed the slope of an area, the mean grade of which was about 6 percent. The plots were 60 feet in length and 24.2 feet in width; they were separated by 15-foot alleys to facilitate individual cultivation and treatment. The soil type of the area is Geary silt loam. It was under cultivation in 1909 when the farm was purchased and has since been planted to such crops as wheat, corn, alfalfa, soybeans, and oats. Oats had been planted in the spring of 1942.

Three groups of 4 plots each allowed the treatments to be applied in triplicate. Each group contained 1 continuously plowed plot, 1 continuously subtilled plot, 1 alternately plowed and subtilled plot, and 1 alter-

nately subtilled and plowed plot.

All plots were assigned in a random manner, and plots 1 and 2, and 5 and 6 were chosen as plots for runoff and erosion studies. In the fall of 1943 these plots were bordered with 1 x 8-inch fir which had been treated with creosote. The lower ends of the plots were fitted with collector devices which in turn guided the runoff and eroded soil into a collector tube at the center bottom of the plots. The area is pictured in Plate I.

A 34-foot collector tile was laid with a 1-percent slope in such a manner that a set of barrels could be placed at its emergence for collection and measurement of runoff water and eroded soil. All eroded material was to be collected in the first barrel and all water was to pass through the same. Dividers were then installed so that the second barrel would collect 1/11 of the runoff and 1/55 would be collected in the third barrel. This arrangement is shown in Plate II. In this way about 8 surface inches of runoff could be measured.

A recording rain gauge was installed to measure time and extent of rainfall. The entire area was seeded to Pawnee wheat in the falls of 1942 and 1943.

MATERIALS AND METHODS

Physical Studies

Moisture samples were taken to a depth of 6 feet in the summer of 1942 and thereafter to a depth of 5 feet. In the first foot, samples representing the 0 to 6-inch and the 6 to 12-inch layer were taken individually; the other samples were taken in 1-foot sections to the desired depth. These samples

EXPLANATION OF PLATE I

General layout of the plots.

PLATE I

EXPLANATION OF PLATE II

Arrangement of barrels and dividers
for collecting and measuring runoff.

PLATE II

were taken with a 7/8-inch sampling tube. The last 4 feet of sample were taken out in 2 sections of 2 feet each and divided to give the desired 1-foot lengths. Three holes were driven per 1/30-acre plot; the samples at corresponding depths were combined, placed in soil cans, weighed, dried at 110° C. for 48 hours, and the percent moisture calculated on dry-weight basis. Plots were sampled at harvest and at seeding time.

Moisture equivalents were determined by the method of Briggs and McLane (1907) for the soil layers at the 7 sampling depths. Moisture present has been calculated and reported as relative wetness or R, where R = moisture/moisture equivalent. R has the advantage of being "corrected" for soil texture and allows comparisons to be made between horizons.

Samples for aggregate analysis were taken with a 6-inch sampling tube. Plots were sampled to a depth of 6 inches about once a month when soil conditions permitted. Three samples were taken at random per plot. Since it was often impossible to take and run samples from all 12 plots in 1 day, determinations were made in such a way that a set of samples always included at least 1 group of the 4 different treatments being applied. The 6-inch cores were placed in heavy paper sacks and taken immediately to the laboratory where they were passed through a 1/2-inch mesh screen. Aggregates were washed from a 100-gram representative sample. The method used was similar to that used by Myers and McCalla (1941) except that the samples were run at field moisture content and were allowed neither to dry nor to slake. They were washed for 15 minutes in distilled water. The rate of submersion was 22 times per minute. The aggregated fraction was that fraction remaining on the sieves at the end of the period of washing. These aggregates were washed into weighed beakers with distilled water, evaporated to dryness

on the steam bath, and the percentage aggregation calculated on the dry-weight basis. The percent aggregates of 3 sizes, namely, greater than 4 mm., greater than 2 mm. but less than 4 mm., and greater than 0.105 mm. but less than 2 mm., were combined to give the total state of aggregation. The un-aggregated fraction consisted of that material less than 0.105 mm. in diameter which passed through the sieves.

The plots were plowed or subtilled as soon as the crop had been harvested and moisture samples had been taken. In the summer of 1942 this was about July 25, and in the summer of 1943 it was about July 15. The plowed and alternately plowed plots received only disking to control weeds until just prior to planting, when they were disked and harrowed. The subtilled plots were worked with sweeps attached to a 2-row lister; the plots were subtilled as needed for weed control and seed planted in the stubble that remained at seeding time without further working of the plots. Considerable difficulty was encountered with the sweep attachment since surface cover tended to collect in front of the sweeps. It was almost impossible to keep the blades at a constant depth. More volunteer was encountered on the subtilled plots than on the plowed plots.

Residue returned to the surface was calculated by sampling at random 5 areas per plot of 3 square feet each. All residue was removed from this area and dried in the oven at 85° C. for 48 hours. The samples were then weighed and the total residue calculated as pounds per acre. The same samples were then ground in a Wiley mill and a 1-gram representative sample ignited in a muffle furnace. The difference in weight was used as a measure of the volatile material turned under in plowing or left on the surface of the subtilled plots.

Microbiological Studise

A microbial analysis was made on the aggregated and unaggregated fractions. Four groups of organisms were included in the analysis; these were (1) totals organisms, (2) fungi, (3) anaerobes, and (4) actinomyces. The total organisms were countsd as all of those organisms which had developed on "totals" media at the end of 7 days; fungi were thoss which had developed on "fungi" media in ths same period of time; anaerobes were counted as all of those organisms developing on "totals" media when incubated under anaerobic conditions; actinomyces were counted as those dry, hard, powdery, slightly raised colonies showing svidence of short aerial hyphae which developed on "totals" media. The media used were those used by Stumbo, Gainey, and Clark (1942).

All plates were incubatsd at 28° C. The anaerobic plates were placed in large desiccators having stopcocks fitted in the lids to facilitate later removal, sealed with "Lubroseal," and anaerobic conditions obtained through the use of a sodium hydroxide-pyrogallic acid mixture. A plate of Azotobacter chroococcum on mannite media was included in each desiccator as an indicator. No growth of A. chroococcum was obtained in any of the experiments.

Aggregates for microbial analysis were separated by the method described above from 100 grams of fresh soil. The 3 fractions were combined and a moisture sample removed; 20 grams of the remainder were washed into a dilution flask with 20 cc. of sterile, distilled water. The samples were shaken for 10 minutes with glass beads to break down the aggregates.

The unaggregated fraction which had been washed with 12 liters of dis-

tilled water was mixed by a specially constructed, electrically-driven stirring rod for 10 minutes, at the end of which time three 10-cc. samples were taken. One of these was placed in a dilution flask; the other 2 were discharged into weighed evaporating dishes. These later were evaporated to dryness at 110° C. The weight of the unaggregated fraction per 10 cc. was used in the calculation of organisms per gram of unaggregated material. Since this technique and equipment had not been used before, a rather extensive study was made of its use.

All operations involved in handling these aggregated fractions and unaggregated fractions were carried out under as nearly aseptic conditions as possible; flame was used to sterilize weighing dishes, spatulas, etc. Since it was impractical to sterilize the great volume of water required for washing aggregates, a sample of wash water was plated for every determination. It was found that no fungi developed in a 1-10 dilution, and the number of "totals" developing in the 1-100 dilution amounted to only 1×10^{-7} of the calculated total count. Hence the counts recorded were not corrected for wash water.

Chemical Studies

Nitrates were determined by Harper's phenoldisulphonic acid method as outlined by Wright (1934). Ten samples were taken per plot at depths of 0 to 3, 3 to 6, and 6 to 12 inches. The samples from corresponding depths were combined for any 1 plot and duplicate analysis made on the composited sample.

Total nitrogen was determined using the Gunning-Hibbard method as outlined in Association of Official Agricultural Chemists (1935) except that

the distillate was absorbed by 4-percent boric acid solution and the ammonia titrated with standard sulphuric acid, using brom cresol green and methyl red as an indicator.

Allison's (1935) modification of Sholenberg's method was used for carbon determinations. All carbon and nitrogen samples were passed through a 100-mesh screen before analysis. In the carbon and nitrogen analysis of the aggregated and unaggregated fractions, only 1 sample could be taken per washing; this was divided and duplicate determinations made.

Method of Sampling the Unaggregated Fraction

The stirring rod used for mixing the samples was tubular in shape and constructed in such a way that the soil suspension was thrown to the inside of a rotating tube by wings and out at the bottom. Known weights of the unaggregated fraction of a soil were placed in the wash jar and mixed for 10 minutes. Samples were removed 1 cm. from the wall of the jar and 2 cm. from the stirring rod; 6 different depths of sampling were tested. Those samples removed at a depth of 24 cm., 1 cm. from the jar wall, gave significantly higher weights of suspension than samples taken at other positions.

When 45.06 grams of oven-dry, unaggregated soil was mixed and sampled by the above method, the weight of sample at a depth of 24 cm. involved an error of 1.6 percent (±0.8). The depth of sampling was chosen as 24 cm., and all samples for bacterial analysis were taken in that position.

It is possible that the position of sampling found to be best in this study might vary with the soil texture. A study of sampling position similar to that outlined should be made for each type of soil used.

After the unaggregated fraction had been washed from a soil sample, a

test of ability to replicate samples by the above technique was made. Results are recorded in Table 2. The F value for duplicates (0.496) is far from being significant, hence sampling values could be readily duplicated. The table also shows from the highly significant F value for date/error a definite difference in state of unaggregation for the sampling dates given.

In connection with Table 1, it should be noted that there is an increase in unaggregated material within the replications under the same date, particularly for the dates May 3 and May 5. This increase in the unaggregated fraction or decrease in the state of aggregation was noticed when attempts were made to replicate samples. It will be dealt with at further length under "State of Aggregation."

Table 1. Data relative to the reliability of the method used for securing a sample of the unaggregated fraction.

Sampling date		Weight of unaggregated material in designated samples			
		1	2	3	4
1943					
May 1	a	41.6[1]	42.3	42.8	42.3
	b	42.8	44.1	43.1	45.4
	Sum	84.4	86.4	85.9	87.7
May 3	a	24.9	40.5	40.6	39.7
	b	21.7	37.3	39.0	39.7
	Sum	46.6	77.8	79.6	79.4
May 5	a	19.4	25.2	37.2	35.4
	b	20.3	26.6	38.5	37.9
	Sum	39.7	51.8	75.7	73.7

[1]Weights in mg. per 10 cc. of suspension.

Table 2. Analysis of variance of data in Table 1.

Source of variance	d.f.	Sum of squares	Variance	F
Duplicates	1	0.844	0.844	0.496
Sampling date	11	1521.41	138.31	81.36**
Error	11	18.70	1.70	
Total	23			

**Highly significant.

EXPERIMENTAL DATA

Surface Cover

Surface cover was sampled as previously outlined and calculated as pounds per acre. The results are recorded in Table 3. It should be noted that in July of 1942 no treatment had been applied. The initial crop had been oats, and since the crop was bound and removed from the field, the weights of cover are considerably less than those for 1943 when the plots were combined and all residues returned to the surface. In July of 1942 the plots are essentially the same as far as surface cover is concerned.

Plowing effectively turned under about 83 percent of the total surface cover as shown by October samples, whereas under subtillage treatment about 49 percent of the total surface cover had disappeared.

If volatile matter is considered, 94 percent had been turned under by plowing, but 75 percent had disappeared under subtillage. Considering that all material was left on the surface under subtillage treatment, some leaching and decomposition must have taken place to account for the large decrease

Table 3. Weight of surface cover at various dates in pounds per acre.

Plot	July 7, 1942				November 15, 1942				July 1, 1943			
	Plow		Subtilled		Plow		Subtilled		Plow		Subtilled	
	Total	Volatile	Total	Volatile	Total	Volatile	Total	Volatile	Total	Volatile	Total	Volatile
1	1612.8	1424.7			105.6	41.1			5219.8	3781.3		
2			1822.7	1633.9			1246.1	390.8			4316.8	2993.7
3			1554.6	1353.2			557.4	226.6			6487.7	4743.1
4	1290.9	1129.1			89.6	42.9			5096.3	3819.2		
5			1329.3	1155.9			431.4	228.7			4310.4	3207.4
6	1470.4	1275.6			195.2	105.5			5142.4	3792.5		
7	1179.8	1026.6			160.0	88.1			5072.0	3538.7		
8			1453.4	1257.8			541.4	270.1			4775.7	3647.2
9			1286.4	1058.4			1331.2	567.5			3946.2	2910.7
10	1536.6	1274.6			174.7	66.6			4613.8	3081.5		
11			1433.6	1099.6			431.4	176.9			4163.2	3124.1
12	1273.6	993.8			146.6	57.3			4567.7	3591.6		
Mean	1394.0	1187.4	1488.0	1259.8	145.3	66.9	756.5	301.1	4952.0	3600.8	4666.6	3434.7
Subtilled-plow (total)			86.0				611.2				-285.4	
Subtilled-plow (volatile)				72.4				234.2				-166.1

in volatile material with a relatively small decrease in total material on the surface. Whether this organic matter has been lost to the atmosphere in the form of carbon dioxide or whether subsequent plowing will make use of it as partially decomposed organic matter has not been determined. McCalla and Duley (1943) point out a similar loss of straw from subtilled plots.

In 1943 the plowed plots yielded more straw than did the subtilled plots. This is in line with the height of plant measurements and yield data recorded in Table 29. An October determination of surface cover was not made in 1943.

The 1943 differences in surface cover are of interest. In 1942 the subtilled plots carried slightly more surface cover than did the plowed plots. This was reversed in 1943 with the plowed plots more heavily covered than the subtilled plots.

Drying Factor or D Ratio

In seeking an explanation of the great variability of the state of aggregation encountered on all plots, and especially of the reversible nature of the state of aggregation when subtilled plot samples were compared with plowed plot samples, there was noted a casual relation between the weather conditions at sampling time and the state of aggregation. The weather conditions which gave marked changes seemed to be those associated with wetting and drying.

Some means of expressing the above conditions was sought. Thornthwaite (1931) gives the PE index as: $PE = \sum^{12} 115(P/T-10)^{10/9}n$, where $\sum^{12}$ is the summation for 12 months, 115 is a constant, 10/9 is a power factor, and P and T are precipitation in inches and temperature in degrees Fahrenheit respec-

tively, and n is equal to 1.

A simpler means of expressing conditions for short periods, for exampls 5 days, was sought, and since drying is directly proportional to temperature and inversely proportional to rainfall, the relation $D = T/(R+1)$ was used, where T is temperature in degress Fahrenheit and R is rainfall. Rainfall was increased by unity in all cases to obviate an infinite value of D at $R = 0$. D also has the advantage of giving the valus of T directly when $R = 0$; the value of T is entirely lost in Thornthwaits's expression in that all values go to 0 when $P = 0$.

When the D ratio was plotted for 5-day periods against time and the state of aggregation was superimposed in like manner, the relation which had been previously noted was indicatsd. A negative correlation was pressnt in all casss. This fact has made the D ratio ussful in the study of aggregation.

Figure 1 shows the D ratio as a monthly and yearly average based on 82 years of records, and as monthly averagss for the periods March, 1942, to December, 1942, and January, 1943, to November, 1943.

It should be noted in connection with this study that the months of August, September, and October, 1942, were wetter as determined by D than comparable months for 1943; also that July of 1942 was much drier than July of 1943. These are important observations in connection with soil moisture and nitrate accumulation data.

The use of D will be dealt with under soil moisture and state of aggregation.

It is recognised that the D ratio leaves much to be desired as far as absolute valuss of drying or wstting are concerned, since it does not take into account relative or absolute humidity. However, it has besn shown

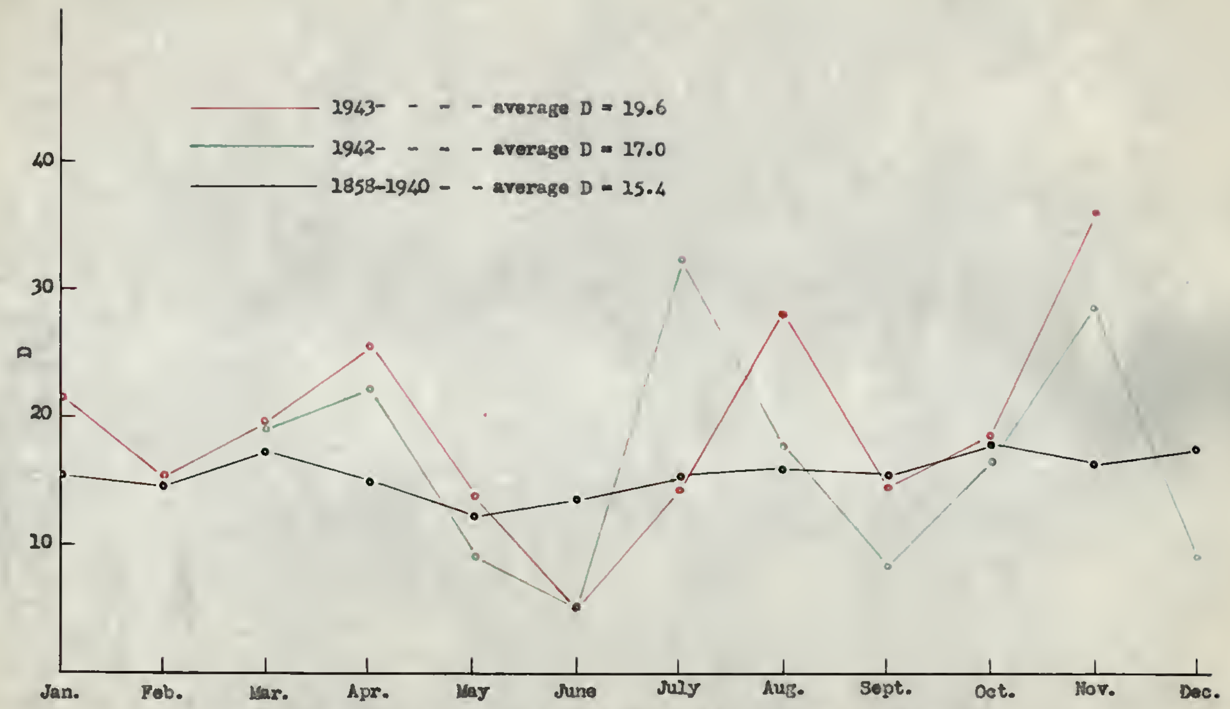

Fig. 1. Monthly values of D from March, 1942, through November, 1943, compared with the monthly averages for the period 1858-1940.

(Hide, 1942) that soil temperatures of bare or fallowed soils in the months studied are greater than those of the air above the soil. So long as the surface is wet, this would mean that in the immediate surface, vapor pressure is higher than in the atmosphere; hence the condition would be a drying one in that zone. It follows that whenever the temperature of a moist soil layer is higher than air temperatures, conditions are those associated with vapor loss.

Moisture Accumulation

The years 1942 and 1943 were both slightly drier than average as shown by the D values 17.0 and 19.6 (Figure 1). However, because of unusually wet Junes in both years, the soil profile on all plots to a depth of 5 feet was relatively moist, giving R values averaging about 0.7 for any 1 depth, and for this reason no striking changes occurred during the period studied as far as increases or decreases at a given depth under different treatment was concerned.

Soil moisture recorded as R, and changes in soil moisture recorded as plus or minus R are given in Table 4 for all sampling depths and for all plots. Plots 4, 7, and 10, which were alternately plowed in 1942, were subsurfaced in 1943 after July moisture samples had been taken. The same is true for plots 3, 8, and 9, which had been subtilled in 1942 and were plowed in 1943.

The results of analysis of soil moisture data are recorded in Tables 5 and 6. It will be noted from Figure 1 that July of 1942 was much drier than average. As a result, at the time of sampling, the entire profile contained the lowest amount of moisture encountered during the period of study. The

Table 4. Soil moisture 0 to 5 feet recorded as R[1] for each depth and date sampled.

July 20, 1942 Moisture equiv-alent	July 20, 1942 R	Sept. 30, 1942 R	Sept. 30, 1942 Gain or loss over 7/20/42	Oct. 12, 1942 R	Oct. 12, 1942 Gain or loss over 7/20/42	July 2, 1943 R	July 2, 1943 Gain or lose over 7/20/42	Sept. 28, 1943 R	Sept. 28, 1943 Gain or loss over 7/2/43	Oct. 12, 1943 R	Oct. 12, 1943 Gain or loss over 7/2/43	Depth in feet
Continuously plowed												
Plot 1												
22.46	0.554	0.822	0.277	0.980	0.434	0.988	0.442	1.007	0.019	0.910	-0.078	0-½
25.62	.748	.944	.194	.976	.226	1.130	.382	1.014	1.012	1.012	-.118	½-1
27.68	.782	.852	.010	—	—	1.004	.222	.948	-.156	—	—	1-2
24.74	.730	.835	.104	—	—	.925	.194	.893	-.032	—	—	2-3
25.66	.740	.748	.028	—	—	.902	.162	.836	-.065	—	—	3-4
26.10	.768	.815	.047	—	—	.936	.168	.848	-.088	—	—	4-5
Plot 6												
24.72	.572	.756	.184	.834	.262	1.032	.460	.960	-.072	.860	-.172	0-½
25.81	.749	.918	.170	.956	.208	1.112	.362	1.004	-.108	.980	-.131	½-1
29.06	.781	.853	.072	—	—	.984	.202	.944	-.039	—	—	1-2
28.26	.720	.816	.096	—	—	.893	.174	.806	-.086	—	—	2-3
26.28	.774	.831	.057	—	—	.935	.161	.834	-.100	—	—	3-4
25.66	.736	.862	.126	—	—	.980	.244	.884	-.097	—	—	4-5
Plot 12												
23.38	.528	.770	.242	.785	.256	1.198	.668	.991	-.208	.922	-.277	0-½
25.86	.704	1.035	.331	.907	.203	1.091	.387	1.028	-.064	.991	-.100	½-1
29.58	.778	.971	.193	—	—	.924	.146	.882	-.043	—	—	1-2
26.18	.818	.891	.073	—	—	1.011	.192	.867	-.144	—	—	2-3
24.49	.800	.912	.112	—	—	.954	.153	.869	-.084	—	—	3-4
24.68	.749	.888	.138	—	—	.983	.234	.867	-.116	—	—	4-5

[1] R = Percent moisture/moisture equivalent.

Table 4 (cont.)

		Alternately plowed (1942)						Alternately subtilled (1943)				
						Plot 4						
23.60	.508	.874	.366	.880	.373	1.066	.490	.960	-.106	.894	-.172	0-½
26.26	.671	.970	.298	.952	.280	1.097	.426	1.070	-.026	.976	-.122	½-1
31.17	.699	.841	.142	—	—	.912	.212	.888	-.024	—	—	1-2
28.06	.694	.814	.120	—	—	.815	.181	.784	-.091	—	—	2-3
24.50	.766	.898	.132	—	—	.943	.177	.852	-.090	—	—	3-4
26.75	.717	.828	.111	—	—	.910	.193	.845	-.065	—	—	4-5
						Plot 7						
24.22	.510	.638	.128	.765	.255	1.130	.620	.956	-.174	.852	-.278	0-½
26.94	.706	.862	.154	.826	.112	1.063	.356	.904	-.159	.904	-.158	½-1
29.10	.736	.836	.098	—	—	1.008	.272	.858	-.149	—	—	1-2
27.30	.646	.752	.106	—	—	.869	.224	.826	-.044	—	—	2-3
25.19	.640	.821	.180	—	—	.892	.252	.864	-.028	—	—	3-4
25.70	.644	.822	.178	—	—	.880	.236	.790	-.088	—	—	4-5
						Plot 10						
24.80	.544	.779	.234	.692	.148	1.122	.577	.891	-.230	.840	-.282	0-½
26.66	.717	.969	.252	.908	.190	1.116	.400	.911	-.206	.920	-.196	½-1
31.45	.736	.797	.061	—	—	.918	.182	.818	-.100	—	—	1-2
27.76	.722	.822	.100	—	—	.891	.169	.798	-.093	—	—	2-3
25.75	.762	.898	.136	—	—	.908	.146	.811	-.096	—	—	3-4
25.98	.788	.865	.077	—	—	.926	.138	.796	-.128	—	—	4-5

Table 4 (cont.)

						Continuously subtilled						
						Plot 2						
22.50	.658	.953	.295	.930	.272	1.098	.440	1.042	-.056	.876	-.220	0-½
25.30	.820	1.003	.182	1.000	.179	1.169	.348	1.118	-.051	1.088	-.080	½-1
29.98	.757	.855	.098	—	—	.948	.190	.873	-.074	—	—	1-2
26.03	.720	.852	.132	—	—	.946	.224	.856	-.088	—	—	2-3
25.30	.720	.838	.188	—	—	.946	.226	.906	-.040	—	—	3-4
26.38	.700	.834	.133	—	—	.927	.226	.801	-.126	—	—	4-5
						Plot 5						
25.37	.492	.836	.344	.820	.328	1.048	.556	.958	-.090	.812	-.237	0-½
27.86	.732	.882	.150	.898	.166	1.058	.326	.952	-.106	.954	-.104	½-1
28.52	.817	.897	.080	—	—	1.005	.188	.925	-.080	—	—	1-2
28.78	.696	.778	.082	—	—	.872	.176	.796	-.076	—	—	2-3
25.55	.734	.838	.104	—	—	.952	.218	.856	-.096	—	—	3-4
26.19	.695	.826	.130	—	—	.908	.212	.844	-.064	—	—	4-5
						Plot 11						
23.03	.472	.708	.237	.829	.358	1.115	.644	1.006	-.109	.954	-.161	0-½
26.01	.710	.883	.172	.913	.202	1.120	.409	.980	-.140	1.010	-.110	½-1
29.70	.754	.888	.134	—	—	.959	.204	.874	-.085	—	—	1-2
25.94	.740	.920	.181	—	—	.953	.213	.864	-.088	—	—	2-3
25.86	.614	.854	.240	—	—	.920	.306	.822	-.098	—	—	3-4
25.87	.650	.864	.214	—	—	.952	.302	.822	-.131	—	—	4-5

Table 4 (concl.)

		Alternately subtilled (1942)						Alternately plowed (1943)				
						Plot 3						
22.52	.670	.984	.314	.970	.300	1.253	.580	1.046	-.207	.970	-.284	0-½
25.06	.628	1.020	.392	.998	.369	1.142	.514	1.048	-.094	1.112	-.030	½-1
30.44	.698	.834	.136	—	—	.959	.301	.900	-.058	—	—	1-2
26.50	.740	.830	.088	—	—	.906	.165	.877	-.028	—	—	2-3
24.88	.714	.855	.140	—	—	.976	.261	.868	-.108	—	—	3-4
25.64	.732	.860	.128	—	—	1.006	.275	.890	-.117	—	—	4-5
						Plot 8						
23.67	.469	.834	.364	.754	.284	1.058	.589	.956	-.102	.878	-.180	0-½
26.70	.660	.964	.303	.867	.206	1.066	.404	.884	-.181	.972	-.094	½-1
27.95	.770	.906	.134	—	—	1.050	.280	.875	-.175	—	—	1-2
27.25	.741	.854	.112	—	—	.928	.187	.808	-.120	—	—	2-3
26.38	.732	.857	.124	—	—	.915	.182	.783	-.132	—	—	3-4
24.98	.696	.887	.192	—	—	.941	.246	.868	-.074	—	—	4-5
						Plot 9						
23.68	.538	.860	.322	.707	.169	1.144	.606	.952	-.191	.855	-.288	0-½
25.00	.773	.941	.168	.902	.128	1.149	.376	.948	-.201	.988	-.162	½-1
27.96	.806	.953	.146	—	—	1.014	.208	.930	-.085	—	—	1-2
27.55	.770	.879	.109	—	—	.909	.140	.832	-.098	—	—	2-3
25.78	.738	.881	.142	—	—	.906	.168	.836	-.069	—	—	3-4
26.04	.688	.877	.189	—	—	.889	.201	.842	-.048	—	—	4-5
Total change in R value:												
Subtilled			6.537		2.964[1]		11.102		-3.674[1]		-2.119	
Plowed			5.488		2.950		10.208		-3.506		-1.916	

[1] Total change for first foot only.

Table 5. Moisture accumulation as shown by total R for 0 to 5 feet.

Date	Treatment				Gain or loss over previous date			
	Plowed	Subtilled	Alternately plowed	Alternately subtilled	Plowed	Subtilled	Alternately plowed	Alternately subtilled
1942 July 20	13.021[1]	12.481	12.207	12.563	—	—	—	—
Sept. 30	15.544	15.513	15.090	16.078	2.523	3.032	2.883	3.515
1943 July 2	17.985	17.900	17.530	18.216	2.441	2.387	2.440	2.138
Sept. 28	16.382	16.298	16.144	15.626	-1.603	-1.602	-1.386	-2.590

[1]Totals of three plots under like treatment.

non-significant F value of 2.57 (Table 6) is to be expected since the treatments at that time had not been applied, and the test is in the nature of a uniformity trial.

Table 6. Analysis of variance of data in Table 5.

Date	Treatment	Depth	Treatment x depth
July 20, 1942			
d.f.	3	5	15
Sum of squares	0.019	0.366	0.024
Variance	0.006	0.073	0.002
F[1]	2.57	29.64**	0.58
Sept. 30, 1942			
d.f.	3	5	15
Sum of squares	0.027	0.126	0.031
Variance	0.009	0.025	0.002
F	2.80*	76.99**	0.61
July 2, 1943			
d.f.	3	5	15
Sum of squares	0.014	0.476	0.018
Variance	0.004	0.095	0.001
F	2.06	43.66**	0.55
Sept. 28, 1943			
d.f.	3	5	15
Sum of squares	0.019	0.296	0.014
Variance	0.006	0.059	0.001
F	3.22*	29.89**	0.50

[1]F values (mean square/plots within treatment and depth mean square).
*Significant.
**Highly significant.

The highly significant F value for depth merely serves to emphasize the variation in soil composition with depth. The profile development in the different plots was, however, relatively uniform as indicated by the moisture equivalents which for the surface soil had values of about 22.5. The moisture equivalent increased to a depth of about 2 feet where the value was 31.5

and then decreased until in the fifth foot it was about 24 as shown in Table 4.

Of interest are the two significant F values for treatment, both occurring in September, that is, shortly after treatment. From the data presented in Table 5 it will be seen that both plowed and subtilled plots had taken up considerable moisture since July but that the subtilled plots had gained more moisture than had the plowed plots. Reference to Figure 1 will show a falling D value from July to September. At this time, then, the differences due to treatment are significant and subtilled plots had taken in a greater portion of the precipitation received.

It would seem, under the conditions encountered, that the value of treatment is at times overshadowed by other factors since the F value for July of 1943 is again non-significant. The growing crop itself from early spring until harvest time perhaps exerts a great influence. Surface cover is also decreasing on subtilled plots through decomposition, etc.

In September of 1943 the F value is again significant. At this time subtilled plots contained less moisture than did plowed plots. Figure 1 shows the differences in the years 1942 and 1943. July was wetter in 1943, whereas August and September were both drier.

From the data it would seem that subtilled plots take in more moisture during wetting conditions, since there is less runoff (Table 26) and less soil dispersion (Lowdermilk, 1930), but when conditions are drying, more moisture is lost from subtilled plots than from plowed plots.

This latter observation is in agreement with the work of Loomer (1942) who concluded from a study of soil moisture movement that, "As long as evaporation does not take place more rapidly than capillary conductivity can

replace the water lost from the surface of the soil, the moisture content of the interior of the soil mass will continue to decrease." Leomer concluded that this happened under certain types of mulches.

Moisture samples were taken to a depth of 1 foot in October coincident with nitrate samples taken at that time. The data were combined with the moisture data for the 0 to 12-inch depth obtained from the September and July samplings. The results for the 0 to 6-inch depth are recorded in Tables 7 and 8. Figures 2 and 3 also show the trend of soil moisture accumulation for these 3 periods for the 0 to 6-inch and 6 to 12-inch layers. These curves depict total R for the given depths and the given periods.

It is worthy of note that the 2 years differ markedly in their D ratios for the 3-month periods and that this difference is well reflected in the trend of soil moisture. The same trends are noted here as were noted in the studies on the 0 to 5-foot profile, that is, the moisture accumulated at a greater rate in the subtilled plots than it did in the plowed plots. Further, when conditions are drying instead of wetting, the rate of decrease in moisture content is greater in subtilled plots than in plowed plots.

The period from September 28 to October 12, 1942, represents a period of warm weather with an almost average D (Figure 1). Except for 1.34 inches of rain on the third of October, little rain fell during this period. There were 9 days with the temperature above 80° F. In general, this was a period of drying; however, plowed plots seemed to take up that moisture which fell and increased an average of 0.133 R per plot in the surface 6 inches. On the other hand, the subtilled plots did not gain in moisture in the surface 6 inches but lost an average of 0.042 R per plot.

The 1943 data are almost the reverse of those obtained in 1942. The

Table 7. Moisture accumulation as shown by mean R for 0 to 6 inches.

Month	Treatment: Plowed 1942	Treatment: Plowed 1943	Treatment: Subtilled 1942	Treatment: Subtilled 1943	Monthly mean 1942	Monthly mean 1943
July	0.5348		0.5499		0.5423	
"		1.0895		1.1196		1.1040
September	0.7734		0.8627		0.8181	
"		0.9855		0.9690		0.9772
October	0.8231		0.8352		0.8292	
"		0.8989		0.8715		0.8852
Treatment mean	0.7104	0.9913	0.7493	0.9867		

Table 8. Analysis of variance of data in Table 7.

Source of variance	Treatment	Year	Month	Year x month	Treatment x year	Treatment x month
d.f.	1	1	2	2	1	2
Sum of squares	0.052	1.209	0.066	0.858	0.008	0.06
Variance	0.052	1.209	0.033	0.429	0.008	0.03
F[1]	1.0	2.82	0.07	79.72**	1.60	5.73**
Least significant difference				0.06		0.06

[1]F values (mean square/plots within treatment, month and year mean square).
**Highly significant.

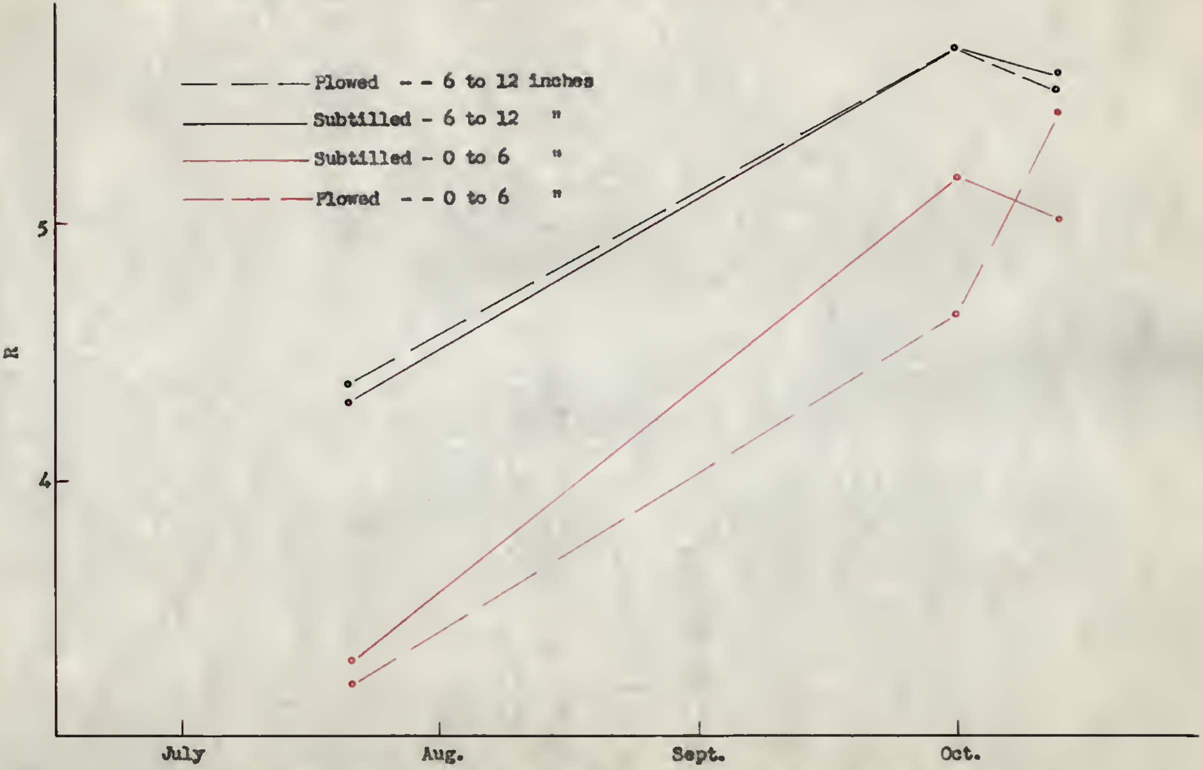

Fig. 2. Trends in moisture accumulation as shown by total R in July, September and October, 1942.

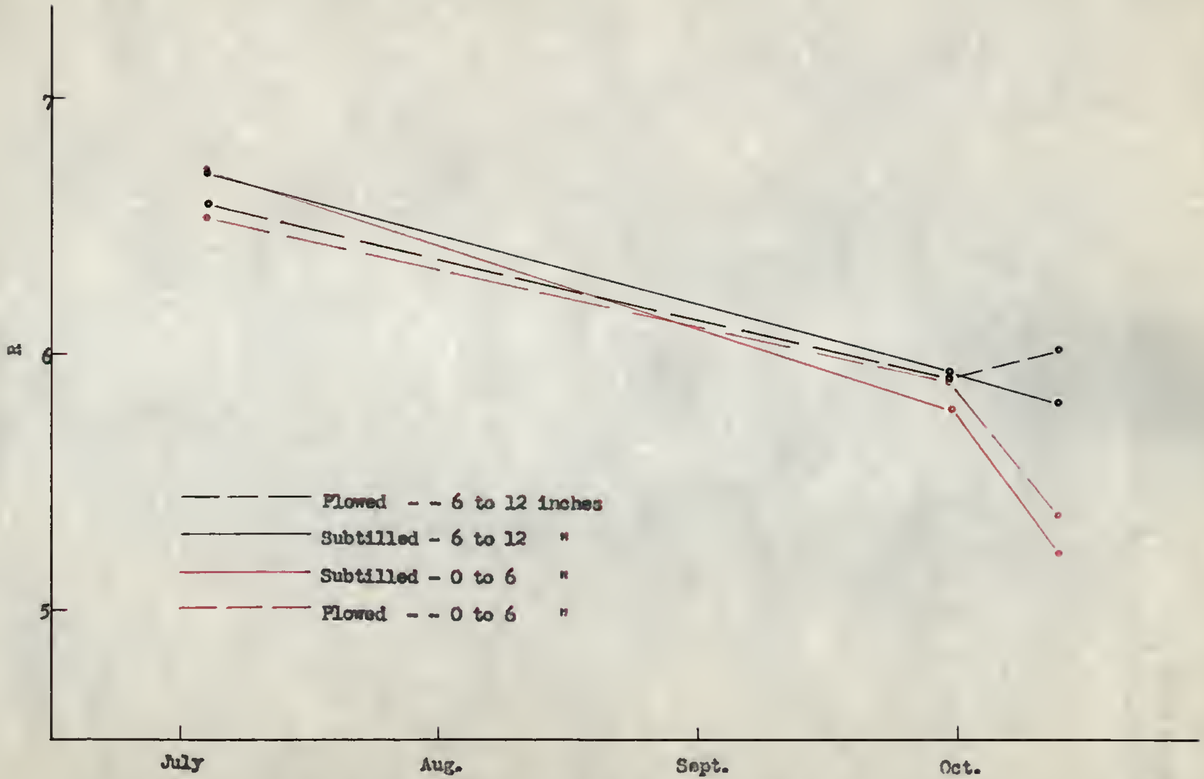

Fig. 3. Trends in moisture accumulation as shown by total R in July, September, and October, 1943.

July D ratio (Figure 1) was low as a result of wetting conditions, and the soil moisture content was high (Figure 5). August, September, and October were drier than the same period in 1942. At the beginning of the period it should be noted that subtilled plots in both the 0 to 6-inch and 6 to 12-inch sections were more moist than were the same sections under plowing. As the value of D increased there was a reversal of this condition, and, as for the September-October period in 1942, R decreased more rapidly for the subtilled plots than it did for the plowed plots. The result at sampling time in October was less moisture under subtilled plots than under plowed plots.

The data for the 0 to 6-inch section of the profile were subjected to an analysis of variance and the results are recorded in Table 8. Treatment, year and month do not reach significance. This may be partially due to the few degrees of freedom and the highly significant interactions. Year x month and treatment x month interactions are highly significant. In the case of the year x month interaction, the 1942 order of accumulation was October, September, and July, with the 2 former falling into 1 group and a definite break between these 2 and July. In 1943 the order of accumulation was July, September, and October, with each month a separate entity. These trends are shown in Figures 2 and 3.

The treatment x month interaction substantiates the indications of the graphs that the treatment affected the accumulation of moisture differently under different moisture conditions. The 2 times when significant differences were encountered were September, 1942, when plowing had accumulated less moisture than subtilling, and July, 1943, when plowing had accumulated loss moisture than subtilling. That these significant differences disappear in both cases when conditions change from wetting to drying, adds further

support to the observations of differences in the drying rates under the 2 types of treatment.

Carbon and Nitrogen Studies

Two weeks prior to treatment and 2 months after treatment in the summer of 1943, samples of the aggregated and unaggregated fractions of soils on all 12 plots were collected from the bacterial samples taken at these times. These samples were dried, ground to pass a 100-mesh screen, and total nitrogen and organic carbon determined on duplicates. It was supposed that any differences which might be found to exist in bacterial numbers would be related to the carbon and nitrogen changes in the 2 fractions studied.

Tables 9 and 10 record the results of the analysis. The data vary widely, and in view of the conclusions of Waynick and Sharp (1919) it is probable that no actual differences exist as far as treatment is concerned. However, it should be pointed out that the difference in both carbon and nitrogen, when the 2 fractions are considered, is actual as shown by the highly significant value of t for nitrogen studies and the significant value of t for carbon. Both carbon and nitrogen are found in larger quantities in the aggregated fractions.

When C/N was calculated, no difference was found between the 2 fractions. This would tend to indicate a similarity of the organic matter which they contain. The amounts of carbon and nitrogen for the periods 2 weeks prior to treatment and 2 months after treatment were corrected for the state of aggregation and the overall carbon-nitrogen ratio calculated. Again no differences were found. The C/N values are essentially the same, considering the wide variation in results. It would seem then that plowing under or leaving on the surface almost 2½ tons of straw per acre had no appreciable or

Table 9. Percent total nitrogen for aggregated and unaggregated fractions.

Date	July 12, 1943				September 14, 1943			
Fraction	Aggregated		Unaggregated		Aggregated		Unaggregated	
Treatment	Plowed	Subtilled	Plowed	Subtilled	Plowed	Subtilled	Plowed	Subtilled
Plot								
1	0.230[1]		0.101		0.201		0.113	
2		0.202		0.090		0.170		0.114
3		0.207		0.088	0.195		0.114	
4	0.225		0.101			0.181		0.100
5		0.177		0.094		0.164		0.115
6	0.155		0.075		0.149		0.097	
7	0.154		0.083			0.146		0.093
8		0.168		0.083	0.162		0.086	
9		0.189		0.092	0.203		0.106	
10	0.186		0.083			0.195		0.099
11		0.106		0.088		0.208		0.100
12	0.185		0.100		0.232		0.106	
Mean	0.183		0.090		0.184		0.104	

<u>t values</u>

Subtilled versus plowed:

22 d.f., $\bar{d}$ aggregated, 0.003 t — 1.13
22 d.f., $\bar{d}$ unaggregated, 0.002 t — 1.01

Aggregated versus unaggregated:

46 d.f., $\bar{d}$, 0.86 t — 17.90**

[1]Average of duplicates.
**Highly significant.

Table 10. Percent organic carbon for aggregated and unaggregated fractions.

Date	July 12, 1943				September 14, 1943			
Fraction	Aggregated		Unaggregated		Aggregated		Unaggregated	
Treatment	Plowed	Subtilled	Plowed	Subtilled	Plowed	Subtilled	Plowed	Subtilled
Plot								
1	2.720[1]		1.471		2.421		1.431	
2		2.409		1.302		2.216		1.643
3		2.501		1.326	2.508		1.554	
4	2.692		1.650			2.385		1.505
5		2.310		1.377		2.016		1.587
6	1.963		1.190		2.023		1.294	
7	1.822		1.240			2.096		1.365
8		2.368		1.256	2.017		1.262	
9		2.249		1.256	2.066		1.493	
10	2.193		1.115			2.374		1.219
11		2.612		1.132		2.381		1.341
12	2.223		1.358		2.366		1.226	
Mean	2.264		1.307		2.239		1.410	
C/N	12.320		14.540		12.320		13.540	

Overall C/N corrected for state of aggregation, July 12 — 13.66; September 14 — 13.55.

<u>t values</u>

Subtilled versus plowed:

22 d.f., $\bar{d}$ aggregated, 1.10 t — 1.25
22 d.f., $\bar{d}$ unaggregated, 1.30 t — 1.68

Aggregated versus unaggregated:

46 d.f., $\bar{d}$, 9.30 t — 2.36*

[1]Average of duplicates.
*Significant.

lasting effect on the carbon, nitrogen or C/N of either the total soil or its aggregated or unaggregated fractions.

A third set of samples was taken at the time bacterial analysis was made 2 weeks after treatment. However, at that time the state of aggregation was low and 1 sample did not yield enough material for bacterial studies and carbon-nitrogen determination. As a result, the aggregated fractions from all like treatments had to be combined in order to obtain sufficient sample for carbon and nitrogen determinations. This was also done for the unaggregated fraction; results of analysis are recorded in Table 11. No definite conclusions can be drawn on so few samples, but some averages might be pointed out.

When the unaggregated fraction alone is considered for all plots, N = 0.093 and C = 1.419. These are not greatly different from other results of carbon and nitrogen analysis on other unaggregated fractions. However, the aggregated fraction yielded values of N = 0.209 and C = 3.022. The value of nitrogen is slightly higher than values found prior to treatment or 2 months after treatment. The value of carbon is considerably higher than that for the same 2 periods. This would indicate that decomposing organic matter made up a greater percentage of the aggregate at this particular time. The overall value of C/N calculated from these data and corrected for state of aggregation was 13.95. Considering the small number of samples and the variability shown by aggregated and unaggregated fractions at other periods of sampling, this value does not differ from the averages presented in Table 10.

The fact that the aggregated fraction yields a value for C/N of 14.45 should not be overlooked since it might indicate a difference in the type of organic matter therein at that time. This would appear from subsequent data

to be a transient type of carbon. This same relation will be pointed out in connection with bacterial studies.

Table 11. Percent organic carbon and total nitrogen for aggregated and unaggregated fractions 2 weeks after treatment.

Treatment	Aggregated fraction		Unaggregated fraction	
	Carbon	Nitrogen	Carbon	Nitrogen
Plowed	3.474[1]	0.166	1.454	0.089
Subtilled	2.584	0.279	1.390	0.096
Alternate plowed	3.153	0.186	1.431	0.092
Alternate subtilled	2.879	0.207	1.405	0.094
Mean	3.022	0.209	1.419	0.093

Overall C/N corrected for state of aggregation -- 13.95

[1]Determinations made on combined soil samples from 3 plots receiving like treatment.

Carbon and nitrogen studies were carried out on the aggregated and unaggregated fractions of virgin sod samples collected at the head of the plots. The results of these studies are recorded in Table 12.

It is of primary interest to compare the values set forth in Table 12 with those for similar fractions recorded in Tables 9 and 10. There has been a widening of the carbon-nitrogen ratio from 11.8 to about 13.5. This is in agreement with observations made by Metzger (1939) for plots in continuous wheat.

Though the number of samples is small, it is worthy of note that values of C/N for the unaggregated fraction are in all cases less than similar values for the aggregated fraction. This was not the case with cultivated soil samples. It would seem that the amounts or types of carbon or nitrogen in cultivated soils differ from sod in these 2 fractions.

Table 12. Percent organic carbon and total nitrogen in aggregated and unaggregated fractions from sod.

Sample	Carbon		Nitrogen		C/N	
	Aggregated	Unaggregated	Aggregated	Unaggregated	Aggregated	Unaggregated
1	3.215[1]	1.910	0.272	0.178	11.82	10.73
2	3.120	2.041	0.250	0.180	12.48	11.34
3	3.416	1.810	0.275	0.162	12.42	11.17
4	3.133	1.780	0.249	0.171	12.58	10.41
Mean	3.221	1.885	0.261	0.172	12.32	10.91

Overall C/N corrected for state of aggregation — 11.82.

[1] Average of duplicates.

The decrease in carbon in the aggregated fraction has been 0.97 over the period of cultivation, whereas a simultaneous decrease in the unaggregated fraction has been only 0.52, a little more than 1/2 as great. In the case of total nitrogen, however, the decrease in the aggregated fraction has been 0.08 and also 0.08 for the unaggregated fraction. The nitrogen then would seem to be similar in both fractions; whereas the carbon, or part of the carbon, in the aggregated fraction is more subject to loss, probably by oxidation than is the carbon of the unaggregated fraction.

Two other changes should be noted in connection with the loss of carbon. In the same manner a decrease in the stability of the aggregate has taken place as can be seen by reference to Table 16. This is indicated by minor seasonal fluctuation in the state of aggregation in sod as compared to cultivated soils. There has been a decided decrease in the number of organisms present in the aggregate as shown by the t value 2.09 for total numbers in sod versus plowing, and t value 3.30 for fungi in sod versus plowing (Table 25).

That either or both of these differences might be related to the disappearance from soil of a certain carbon fraction when that soil goes into cultivation is not impossible.

State of Aggregation

The state of aggregation on the plots was studied between February and December of 1943. The results varied widely. With the introduction of the D ratio, however, a rather definite inverse relation was found to exist between it and the state of aggregation. The state of aggregation and soil moisture were then correlated and the results seemed to offer an explanation

of the erratic nature of the determinations between periods and between treatmente. Reference to Figure 4 will show that a rise in soil moisture results in an increase in the state of aggregation, but that this increase is greater under subtillage than it is under plowing. The reverse is the case as the soil dries.

It should be kept in mind, however, that treatments of short duration had been applied. Under extended treatment the same picture might not be obtained due to changes resulting from tillage methods influencing the organic matter, etc. It is difficult to harmonize the results obtained by such workers as Jenny (1933), Elson (1943), Browning (1937) and Baver and Rhoades (1932) concerning the beneficial effect of incorporated organic matter on soil aggregates with those of Alderfer and Merkel (1943), Van Doren and Stauffer (1943) and others who have obtained better structure in soils by leaving the residues on the surface. Since the latter workers obtained their results in Pennsylvania and Illinois respectively, under conditions of relatively low evaporation in comparison with that occurring in Kansas, it would be expected that the subtilled plots would, on the average, contain more moisture than would the plowed plots. It is possible that the relations found by the latter workers have been moisture relations and not a direct result of treatment.

The data on the state of aggregation for the 11 periods studied are set forth in Table 13. The figures recorded are the averages of duplicate determinations on the 6 plots receiving the treatment designated and are the percentages of the dry weight of the soil aggregates greater than 0.105 mm. obtained by wet sieving. The results of statistical analysis, together with the least significant differences, are recorded in Table 14. Over the

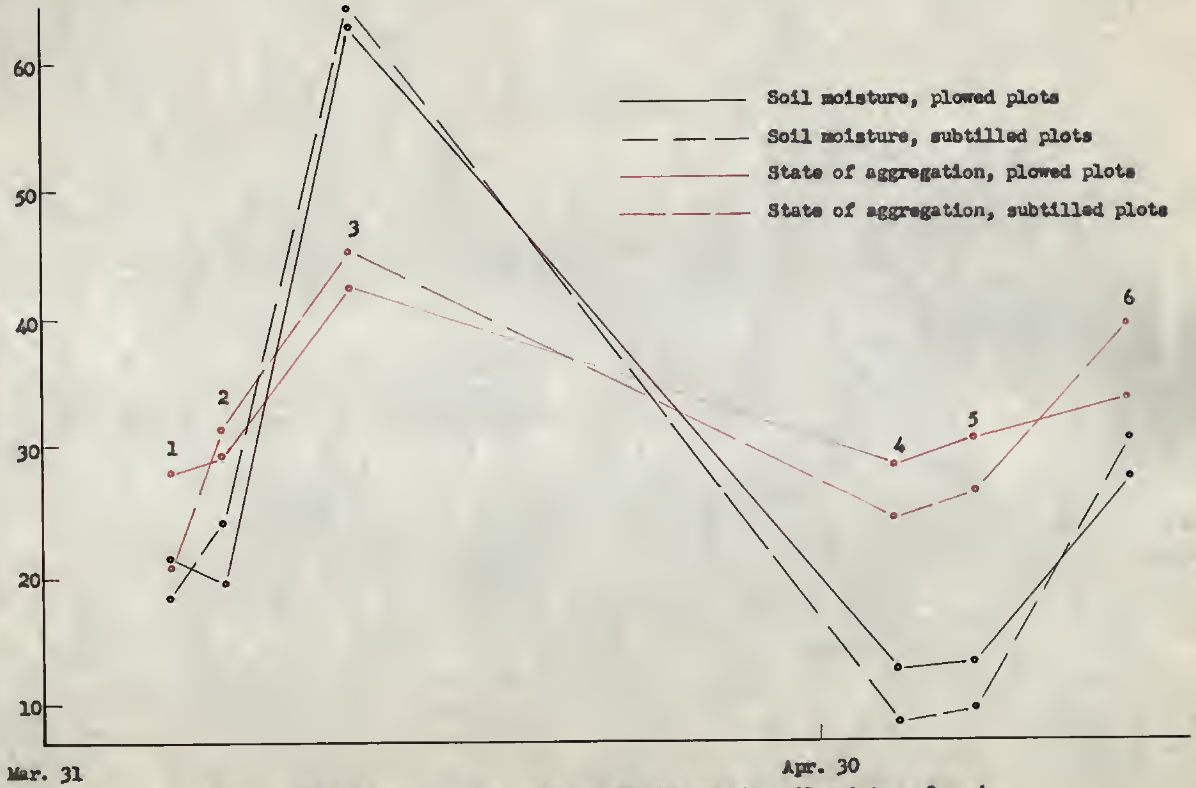

Fig. 4. The relation of the state of aggregation to soil moisture for six periods on subtilled and plowed plots April 5 through May 7, 1943.

Table 13. State of aggregation in relation to position, period and treatment.

Position	Period 1	2	3	4	5	6	7	8	9	10	11	Position mean	Treatment
West	24.65[1]	27.52	36.01	24.02	24.96	26.24	36.08	42.20	33.08	27.18	44.80)	32.36	Plowed
"	15.92	34.81	43.29	22.18	20.88	34.05	47.88	43.74	32.69	25.89	43.94)		Subtilled
Center	38.84	35.68	52.30	29.84	40.62	41.39	47.36	46.31	39.75	36.03	40.20)	39.18	Plowed
"	30.16	35.08	50.89	26.74	34.62	45.20	39.72	51.88	34.36	20.99	45.62)		Subtilled
East	21.12	25.17	40.02	30.66	24.64	33.08	40.64	40.07	40.75	19.62	22.59)	30.04	Plowed
"	16.57	24.04	41.29	23.57	22.99	33.68	38.08	40.69	32.26	21.54	29.99)		Subtilled
Period means	24.54	30.38	43.96	25.86	28.12	35.60	41.64	44.15	35.23	25.21	37.86		

[1]Mean of six plots under like treatment.

Table 14. Analysis of variance of data in Table 13.

Source of variance	Treatment	Position	Period	Treatment x position	Treatment x period	Period x position
d.f.	1	2	10	2	10	20
Sum of squares	26.447	1957.810	6663.656	129.539	525.558	1378.934
Variance	26.447	978.905	666.365	64.769	52.555	68.946
F[1]	0.59	14.20**	9.66**	1.40	11.38**	1.49*
Least significant difference		3.65	7.03		7.83	9.61

[1]F values (mean square/plots within treatment, period and position mean square).
*Significant.
**Highly significant.

11 periods studied, the state of aggregation does not differ significantly with treatment. For the 11 periods, $\bar{x}$ for the subtilled plots was 33.4 and 34.3 for the plowed plots.

From the highly significant F value for position, its least significant difference, and from the position means, it can be seen that the west and east ends of the plots did not differ significantly in state of aggregation, but that the center of the plots differed from either of these. The positional difference may have been due to the presence of an old dead furrow near the center of the plots. It does serve to point out a higher and more nearly stable state of aggregation existing below the furrow slice. The differences, however, should not be attributed to this alone, since the incorporation of considerable organic matter through treatment has removed actual subsurface conditions, and since different moisture relationships would be encountered.

The F value for period was also highly significant. The least significant difference and period means are recorded. The period showed no regularity in frequency of high or low states of aggregation. When periods are grouped according to significant differences, periods 8, 3, and 7 fall into the group of highest state of aggregation. Conditions were wetter than average in these 3 cases. The intermediate group of periods include 11, 6, and 9, with periods 2, 5, 4, 10, and 1 yielding the lowest state of aggregation. These trends are pointed out in Figure 4 for the first 6 periods of sampling.

The F value for treatment x period was also highly significant. While means are not given, differences at 1, 4, 5, and 6 (Figure 4) fall within the range of significance, and the differences at 2 and 3 approach the 5-percent

level. Reversals in treatment effect as shown also occurred at later dates of sampling.

Means of determinations within period and position are not given, but the significant F value leads to the conclusion that the center and east end of the plots are more similar than are the west end and center. Further, the differences between the center and east end seem to be less in wet periods than in dry. An interchange of position between the east and west ends of the plots may be tied up with differential rates of drying or wetting.

Correlation coefficients were calculated relating the state of aggregation with soil moisture. These are recorded in Table 15. The observations made elsewhere concerning the differential rates of wetting and drying with treatment are again borne out by the study of aggregation under these 2 treatments. The trends of soil moisture and state of aggregation follow a very definite pattern as shown in Figure 4. It will be seen that there are 3 reversals in the soil moisture curve and that these reversals occur in both wetting and drying periods. The tendency of moisture to increase and decrease more rapidly under subtillage than under plowing is shown in the trend of the curves. When the state of aggregation curve is considered, there is the same general tendency toward change. The state of aggregation increases and decreases more rapidly under subtillage than under plowing, the wet periods resulting in higher and the dry periods resulting in lower states of aggregation. The conclusions reached are strengthened by the highly significant F value for treatment x period and by Figure 4 where significant differences have been pointed out.

It is considered highly important that the state of aggregation should be positively correlated with soil moisture, for some soils, in view of the

varied procedures used for aggregate analysis. The methods used in this study would indicate that a true picture of aggregate action toward rainfall can be obtained only through an analysis of the soil as it comes from the field. However, data do not conclusively show that trends found in the state of aggregation of moist samples would not persist after air drying. It is possible that many of the contradictory results that have been obtained in studies of the state of aggregation and of the effects of cultivation practices can be explained by soil moisture relationships as shown here.

Table 15. Correlation of state of aggregation and soil moisture content.

Treatment	Position		
	West	Center	East
Plowed	0.396	0.502*	0.508*
Subtilled	0.660**	0.528*	0.638**

*Significant.
**Highly significant.

In line with the carbon and nitrogen studies on sod, state of aggregation studies were also made. Table 16 shows a state of aggregation 20.46 units higher under sod than under plowing. It has been calculated that the percentages of carbon for sod and plowing were 2.74 and 1.69 respectively. The greater decrease in organic carbon falls to the aggregated fraction. This loss in carbon and decrease in aggregation is in agreement with the observations of Ackerman and Myers (1943).

Another point of interest in Table 16 is the more nearly stable condition of the aggregates under sod than under plowing. The deviation from the mean for the 5 periods of sampling, disregarding algebraic sign, was 11.18 units for sod and 31.31 units for plowing.

Table 16. Variability and state of aggregation under sod and under plowing.

Date	Sod	Plowed
November 12, 1943	64.05	38.67
"	61.86	45.44
November 15, 1943	62.89	50.02
November 18, 1943	63.73	41.22
November 22, 1943	68.67	37.56
December 3, 1943	63.33	48.45
Mean	64.08	43.56

10 d.f., $\bar{d}$, 20.52 t — 17.75**

**Highly significant.

The samples removed for aggregate analysis from plowed and subtilled plots seemed to show a visible difference in their structure. In periods of wetting, the subtilled samples were more compact and platy in structure, with a tendency to form clods. On the other hand, the profile from plowed plots had a well developed granular structure; there were no definite fracture planes and the aggregates were well separated. There was also decomposing and undecomposed organic matter throughout the plow zone which did not appear in the plow zone of the subtilled plots.

These differences are shown in Plates III and IV. The samples were taken in the field, trimmed to size with a spatula, cut about half way through for the entire length, and broken open. Cross sections were taken with a 6-inch sampling tube and broken without cutting, about 3 inches below the surface.

EXPLANATION OF PLATE III

Vertical and cross sections of sample taken from subtilled plots.

PLATE III

EXPLANATION OF PLATE IV

Vertical and cross sections of sample taken from plowed plots.

PLATE IV

<u>Absorption of Water by Aggregates.</u> In the course of investigating the state of aggregation and bacterial numbers it was noted that unit weights of aggregate taken from sod were losing more water on drying than were the unit weights of aggregate taken from cultivated soils. This observation was pursued at some length; the results are presented in Table 17.

Table 17. Water-holding capacity of aggregates from sod and plowing.

Date	Water-holding capacity expressed as percent		
	Sod	Plowed	Sod/plowed
November 11, 1943	72.22	52.00	1.38
"	68.57	49.11	1.39
November 15, 1943	63.43	53.47	1.18
"	68.03	52.94	1.28
November 18, 1943	78.86	55.74	1.41
"	71.53	45.95	1.56
November 20, 1943	64.29	61.97	1.04
"	57.40	63.64	0.90
"	66.67	55.21	1.20
"	67.66	58.06	1.16
Mean	67.87	54.81	

18 d.f., $\bar{d}$, 13.06 t — 15.85**

**Highly significant.

That there was a more labile carbon fraction present in the sod samples studied than in the cultivated soils (p. 53) has been pointed out. Among other workers, Foustel and Byers (1936) have pointed out the increase in water-holding capacity of the soil which accompanies an increase in organic matter. It is possible that the loss of this labile carbon fraction with extensive cultivation may account for the loss in water-holding capacity observed.

It should be noted that water uptake per gram of aggregate averages 0.1306 grams higher under sod than under plowing. Assuming 2×10^6 pounds in the furrow slice, the water taken up by the aggregated fraction under sod exceeds that for the same fraction under plowing by 130.6 tons per acre. This is about 1.15 surface inches if total aggregation is assumed, or about 0.72 surface inch for 63 percent aggregation. In light of this calculation there are factors other than surface cover which influence the water relations of sod.

Changes in the State of Aggregation on Wetting. The observations made on field samples concerning the state of aggregation and its correlation with the percent of soil moisture were studied in the laboratory on air-dried soils and slowly moistened soils. Six-inch samples were removed from the field and allowed to dry at room temperature. From these samples, 3 fractions were separated by dry screening, using the same size screens which had been used for the wet sieving process.

The amount of each of the 3 fractions used is recorded in Table 18. One series was allowed to take up 30 percent of its weight of water by capillarity. Evaporation was then restricted. Another series was treated in the same way except that no water was added. The samples were allowed to stand for 24 hours in the laboratory. At the end of this time they were wet sieved and the state of aggregation determined. Results are recorded in Table 18.

It will be noted that in soils which were air-dry there was a breakdown of fractions A and B with an increase in fraction C and in the unaggregated fraction. This confirmed preliminary observations.

Russell (1938) has suggested that the polar nature of water is of great

Table 18. Changes in the state of aggregation following wetting or drying.

Size of fraction in mm.	Greater than 4	Greater than 2 but less than 4	Greater than 0.105 but less than 2	Unaggregated, less than 0.105
	(A)	(B)	(C)	(D)
Weight of original dry sieved separate	40	30	20	
Weight of water-stable aggregates 24 hours after wetting:				
Sample 1	29.1[1]	27.6	25.6	7.7
Sample 2	30.7	25.7	23.1	10.5
Weight of water-stable aggregates without previous wetting:				
Sample 1	4.6	10.8	38.9	35.7
Sample 2	5.4	9.1	38.0	37.5
Average difference wet-dry	24.9	16.7	-14.1	-27.5

[1]Average of duplicates.

importance in the binding of the soil particles into aggregates. Yoder (1936) points out the disintegration of dry aggregates on rapid wetting and suggests that entrapped air may be the cause. Both of these could account for the observations. However, Kolodny and Joffe (1939) were able to show a greater dispersion of soils on wetting than was found in the same soil if it were dry. Browning and Milan (1941) demonstrated that this dispersion was dependent upon the soil type and upon the amount of organic or inorganic colloid present in the soil.

Rapid Changes in the State of Aggregation. From previous studies on the state of aggregation, it had been observed that a rapid change took place as successive determinations were made on the same field sample. This was pointed out as an increase in the unaggregated fraction (p. 29). The change resulted in a decrease in the state of aggregation and was most noticeable in the cooler spring and fall months. Since this decrease caused difficulty in attempted replications, and since drying had given indications of adversely affecting the state of aggregation, an attempt was made to find the cause of the decrease in soil moisture relationships.

Samples were removed from the field in the usual manner; 1/2 of the sample was taken into the laboratory and left intact at room temperature for 1-1/2 hours. The other 1/2 was left where the temperature was somewhat above freezing. Aggregates were washed from sample 1 after standing in the laboratory for 1-1/2 hours and from sample 2 after it had remained outside for 2-1/2 hours. The data are presented in Table 19.

At the end of 1-3/4 hours the moisture content of sample 1 was the same as was the moisture content in sample 2 at the end of 38 minutes, but the state of aggregation was 8.2 units higher in the latter case. This would

indicate that some factor other than moisture also affects the state of aggregation. Among the factors which might cause this change would be changes in temperature, vapor pressure, and carbon dioxide concentration. Rough temperature determinations did not indicate any rapid temperature changes in the soil mass, and it is apparent that the change is a rapid one and of a logarithmic nature. It has been pointed out that the change in moisture content is small in proportion to the change in the state of aggregation.

Table 19. Short-time changes in the state of aggregation.

Sample 1			Sample 2		
Time in the laboratory (hours)	Percent moisture	State of aggregation	Time in the laboratory (minutes)	Percent moisture	State of aggregation
1-1/2	26.90	43.91	3	27.55	55.21
1-3/4	26.58	42.65	18	27.23	54.14
			38	26.58	53.26
			90	26.10	40.72

It has been generally observed that concentrations of carbon dioxide in the soil may readily be 10 times that in the atmosphere. In moist, cool soils this would lead to a high concentration of carbonic acid and a soil colloid fairly well saturated with hydrogen ions. Such a condition would result in the flocculation of soil particles. A dissociation of carbonic acid and a decrease in hydrogen pressure at the surface of the colloid would be brought about by aeration, slight rises in temperature, and changes in vapor pressure gradients which would accompany removal of the soil mass to the warm, dry air of the laboratory. This would bring about a more negatively-charged particle and a co-repelling action or dispersion.

In view of the time factor and small decreases in moisture content of

the soil in the laboratory, such a mechanism as suggested above might account for the results that have been noted.

Microbiological Studies

A preliminary study of bacterial numbers was undertaken using the sampling technique which had been developed to determine its usefulness in gaining representative samples of bacterial numbers from the unaggregated fraction. At the same time it was desired to determine the effect of time of shaking the aggregated fraction on total counts.

The soil samples were washed, mixed, and unaggregated samples taken as previously described. The aggregated fractions were placed in dilution flasks containing 90 cc. of sterile, distilled water and shaken with glass beads for the lengths of time recorded.

An amount of total soil from the same field samples comparable in weight to that of the aggregated fraction was also shaken with glass beads and analyzed quantitatively for bacterial and fungal numbers.

The results are recorded in Table 20. All counts given are averages of 12 plates—the results of quadruplicate plates in 3 trials. The same trend was evident in all 3 trials.

It will be observed that 10 minutes is the optimum time of shaking to give maximum numbers. Prior to that time it would seem that the aggregate is not completely disintegrated, and beyond 10 minutes a grinding effect is probably encountered which reduces the number of viable organisms.

When the observed counts for fungi and total organisms in the aggregated and unaggregated fractions after 10 minutes shaking are adjusted for state of aggregation, the calculated counts for total soil agree well with

the observed counts.

It was desired to obtain the aggregated fraction counts and unaggregated fraction counts from the same soil sample. This could not be done if total soil were used, and since the results obtained from the use of both fractions agreed well with the results from total soil, samples were plated from the aggregated and unaggregated fractions of the same sample.

Table 20. Numbers of total soil organisms and fungi as affected by time of shaking.

Time of shaking (minutes)	Organisms per gram of oven-dry soil x 10^{-4}			
	Aggregated fraction		Unaggregated fraction	
	Total	Fungi	Total	Fungi
6	7,404.88	16.81		
10	11,853.34	19.64	13,543.45	36.99
14	8,423.93	17.37		
18	6,297.42	13.55		
		Total soil		
6	9,149.01	28.15		
10	12,057.93	30.07	12,717.66[1]	28.52[1]
14	11,166.48	35.66		
18	10,949.37	26.27		

State of aggregation — 48.86.

[1]Calculated from the state of aggregation and numbers of organisms in each of the two fractions.

By the use of direct methods of analysis, an attempt was made to gather information concerning the actual relation of the microbial population to the soil aggregate. The methods used were developed in such a way that the naturally occurring aggregated and unaggregated fractions could be studied. It was reasoned that should microorganisms have a direct effect on the state of aggregation, they should be found associated with that fraction. Hence

the method used was developed to allow counts to be made of those organisms tied up within or associated with the aggregate and also of those organisms associated with the unaggregated fraction from the same sample.

Bacterial analyses were made on the plot at 3 periods in the summer of 1943; these periods were (1) prior to treatment, (2) 2 weeks after treatment, and (3) 2 months after treatment. The results are recorded in Tables 21 and 23. Trends of populations are also shown graphically in Figures 5 and 6.

Fungal counts are found in Table 21. By methods of analysis of variance (Table 22) the only significant difference is the position x period interaction. While this shifting of the position of maximal count is not explainable from the data presented, it may be related to soil moisture. Although the periods differ as shown by their means, the data do not show significance, which is probably due to the interaction. The trend of counts is shown in Figure 5 together with the state of aggregation curve and the soil moisture curve; the change in count seems to be closely associated with the change in the state of aggregation or vice versa. Soil moisture changes do not seem to be related to changes in the fungal population. A possible explanation of the depressed curve for subtillage shortly after plowing and the almost level or elevated curve for plowing, may lie in the trend of the total organisms curve for the aggregated fraction (Figure 6). Competition for food would be keen under such circumstances. Plowed plots would have in the furrow slice a ready supply of fresh organic matter, whereas subtilled plots would not have such a supply. In such a situation, although the bacterial population under plowing increased many fold, there would remain more undecomposed organic matter for the fungal population. In the case of subtilled plots, the small amount of available organic matter at the surface of the

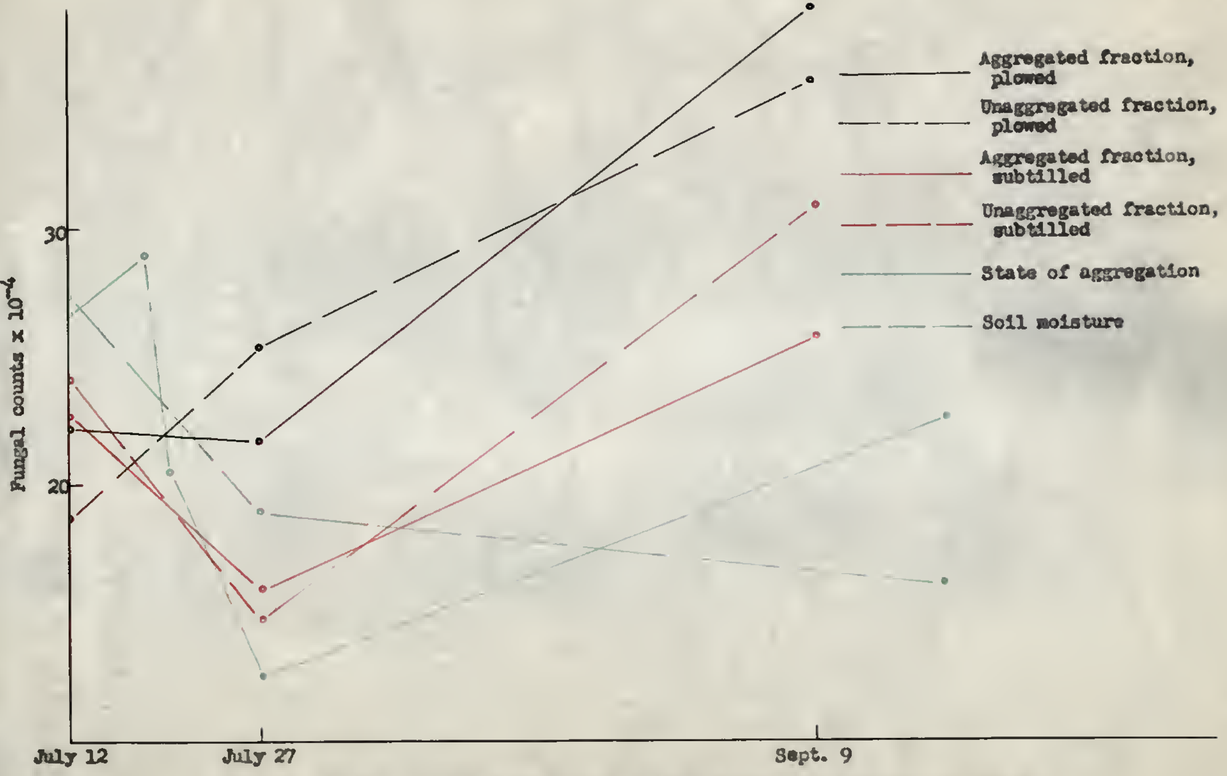

Fig. 5. Average fungal counts in the aggregated and unaggregated fractions compared with the state of aggregation and soil moisture.

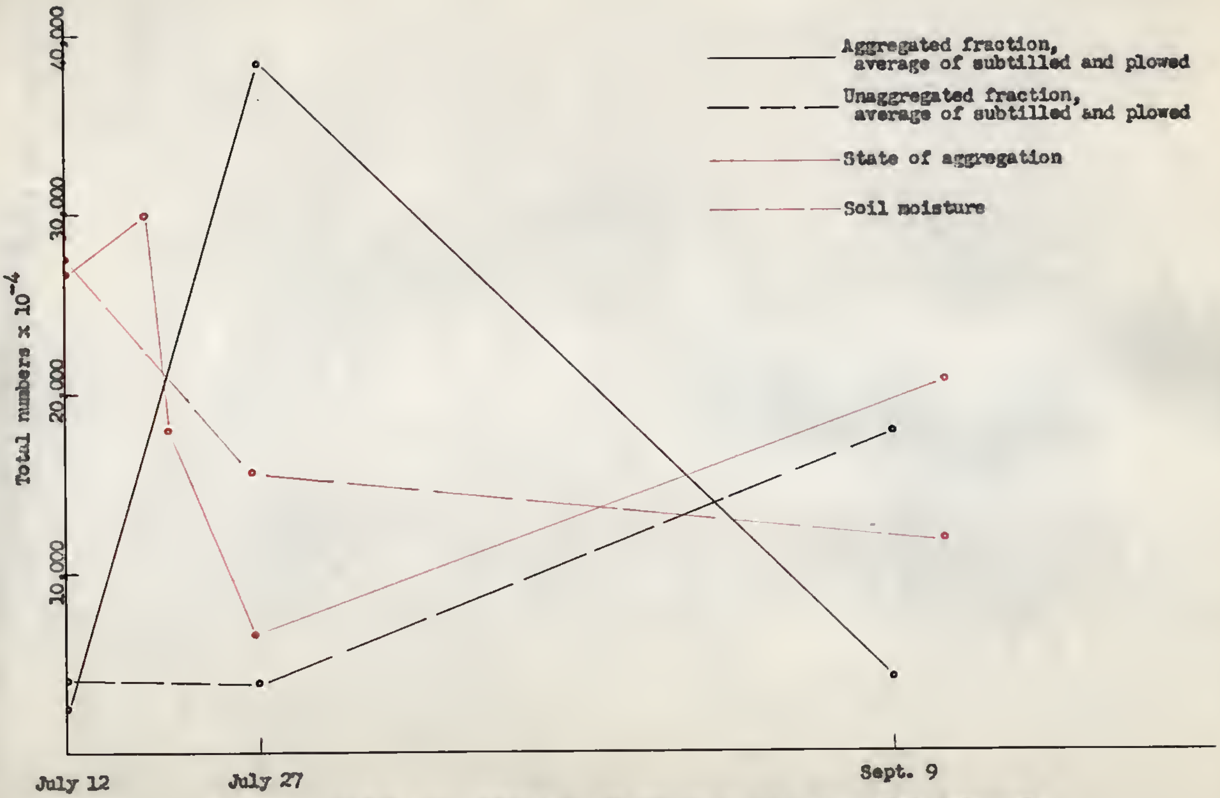

Fig. 6. Average total numbers in the aggregated and unaggregated fractions compared with the state of aggregation and soil moisture.

Table 21. The effect of treatment on fungal counts.

Position in plot	Date: July 12, 1943	July 27, 1943	September 9, 1943	Position mean	Treatment
West	10.26[1]	37.18	30.36	27.60	Plowed
"	19.28	18.26	33.98	23.48	Subtilled
Center	64.44	26.47	34.08	41.66	Plowed
"	23.62	19.04	25.54	22.73	Subtilled
East	18.94	6.56	48.88	24.80	Plowed
"	28.02	6.58	25.25	18.28	Subtilled
Date mean	25.76	19.01	33.01	26.50	

t values from above data, aggregated versus unaggregated

Date	July 12, 1943	July 27, 1943	September 9, 1943
d.f.	22	22	22
t	1.00	0.16	0.07

[1] All counts are averages of 12 plates x 10^{-4}.

Table 22. Analysis of variance of data in Table 21.

Source of variance	Treatment	Position	Date	Treatment x date	Treatment x position	Position x date
d.f.	1	2	2	2	2	4
Sum of squares	1338.772	1250.226	2383.790	11.612	979.466	4537.123
Variance	1338.772	625.113	1191.896	5.820	489.732	1134.280
F[1]	3.41	0.55	1.01	0.01	1.24	2.89*

[1]F values (mean square/plots within treatment, date and position mean square).
*Significant.

soil would be monopolized by the bacterial population and as a result the fungal population would be depressed.

Because of lack of treatment and period differences, counts on the aggregated fraction for the 2 treatments were combined as were counts on the unaggregated fraction. A t test was made to determine any differences which might exist in these 2 fractions; the values of t are recorded in Table 21. In the summer periods, no significant difference in counts associated with the 2 fractions could be detected.

Counts of total organisms were made in the same manner and at the same time as fungal counts; the results are recorded in Table 23 and Figure 6. It is of interest that the same significant interaction, period x position, was obtained with total counts as with fungal counts. There is no explanation for the observation. Results of the analysis of variance are the same as with fungal counts in other respects. Hence a similar t test was made on the data for total counts. Table 23 shows 2 significant differences. The aggregated fraction was significantly higher in total numbers 2 weeks after plowing and subtilling; this rise is shown in Figure 6. Two months after treatment the unaggregated fraction was significantly higher in total numbers, also shown in Figure 6.

Reference to Table 12 will point out the fact that a different type of organic matter, as indicated by the carbon-nitrogen ratio, was present in the aggregated fraction under sod from that in the unaggregated fraction. This has been discussed as a labile type of carbon in that the aggregated fraction loses almost twice as much carbon as does the unaggregated fraction on a unit weight basis when land goes into cultivation. Assuming that the source of this carbon fraction is the root system existing under sod, there is present

Table 23. The effect of treatment on total number of organisms.

Position in plot	Date: July 12, 1943	Date: July 27, 1943	Date: September 9, 1943	Position mean	Treatment
West	1,828.84[1]	13,327.74	16,741.06	10,332.55	Plowed
"	1,688.42	16,875.71	14,555.82	11,040.05	Subtilled
Center	3,460.92	44,378.38	12,566.77	20,135.35	Plowed
"	5,501.22	44,985.18	10,054.88	20,140.42	Subtilled
East	4,053.70	3,913.31	9,804.38	5,090.46	Plowed
"	3,750.82	4,526.20	2,708.67	3,645.48	Subtilled
Date mean	3,380.65	21,334.56	11,071.97		

t values from above data, aggregated and unaggregated

Date	July 12, 1943	July 27, 1943	September 9, 1943
d.f.	22	22	2
t	1.50	3.22**	4.01**

**Highly significant.

Table 24. Analysis of variance of data in Table 23.

Source of variance	Treatment	Position	Date	Treatment x date	Treatment x position	Position x date
d.f.	1	2	2	2	2	4
Sum of square	6,545.460	2,875,925.680	3,894,543.780	25,153.640	102,935.060	4,525,230.436
Variance	6,545.460	1,437,976.340	1,947,276.890	12,576.820	51,467.530	1,131,370.608
F[1]	0.002	1.010	1.020	0.030	0.160	3.50**

[1]F values (mean square/plots within treatment, date and position mean square).
**Highly significant.

at all times a situation similar to that in the cultivated field after residues are plowed under. As residues turned under or sloughing off from roots are attacked by organisms, the microbial population in that immediate area increases. The excretion of waste products and mucilaginous substances would tend to bind particles together and the result would be an aggregate (Martin and Waksman, 1940). However, when the supply of energy was exhausted, the aggregate would deteriorate and the microbial population would be released to the unaggregated fraction. Although these temporary aggregates would be many, their effect would be masked in total soil analysis, since they would make up only a small percentage of the total aggregated fraction. It is of interest to note that the state of aggregation was only 12 to 14 percent at the time of analysis. It has also been pointed out that the organic carbon in the aggregated fraction seemed to increase at this time. From the results of Waynick and Sharp (1919) it would seem that such small amounts of organic matter as are added from a crop's residue should not show such an appreciable change in organic carbon. It should be remembered, however, that if the greater part, say 70 to 80 percent, of the decomposing organic matter is associated with the aggregated fraction and that fraction occupies only 12 to 14 percent of the soil mass, a tremendous increase in organic carbon results in that fraction.

The same line of thought should be pursued in connection with the bacterial numbers curves of Figure 6. A difference of 35×10^4 is observed for the counts in the 2 fractions, but this difference is associated with but 12 to 14 percent of the soil mass. Should the total soil mass be analyzed instead of an aggregated fraction, this difference would be diminished and a more nearly normal curve of numbers would result.

Table 25. The microorganic population of cultivated and virgin soils per gram of designated fraction.

	Total organisms				Fungi			
	Cultivated		Sod		Cultivated		Sod	
	Aggregated	Unaggregated	Aggregated	Unaggregated	Aggregated	Unaggregated	Aggregated	Unaggregated
	4,693.92[1]	13,452.46	11,309.98	23,816.83	36.67	18.63	72.79	41.06
	9,325.63	13,817.54	12,966.86	18,845.40	29.57	15.27	60.29	43.59
	6,943.99	10,787.92	6,287.63	17,212.64	19.95	18.09	74.35	37.26
	14,410.10	10,801.12	9,176.16	20,166.82	57.14	19.23	35.50	27.42
	8,606.25	8,394.80	8,988.44	11,678.60	15.19	19.33	34.88	23.95
	3,272.95	7,518.00	11,094.25	13,184.38	19.75	18.80	33.45	26.37
	10,662.84	8,637.20	9,355.39	13,184.86	26.32	19.33	15.89	27.55
	9,574.20	9,024.05	8,213.08	10,122.50	26.60	19.06	25.57	19.23
	11,800.62	10,094.18	12,024.63	11,557.50	26.83	21.11	62.29	28.99
	17,726.10	6,948.75	8,772.09	10,810.80	30.93	21.12	57.21	26.06
Mean	9,752.20	9,947.60	9,819.85	15,057.83	26.22	18.99	47.22	30.14
	Actinomyces				Anaerobes			
	161.35	—	470.37	483.10	163.15	422.80	275.47	1020.50
	266.59	572.55	493.25	666.64	218.08	672.60	306.84	202.45
	259.70	740.03	138.07	961.60	48.72	64.57	—	—
	259.19	418.00	355.03	632.80	40.02	90.86	—	—
	303.75	748.20	116.28	299.40	67.66	106.98	—	—
	227.17	501.20	289.90	548.47	66.34	79.73	—	—
	236.84	181.20	423.80	306.15	60.05	108.55	—	—
	319.14	224.20	281.30	404.90	46.79	46.27	—	—
	100.86	263.90	460.40	100.50	148.00	70.98	180.64	185.93
	256.90	545.00	144.90	102.70	67.05	101.39	208.95	248.07
	—	—	—	—	69.85	94.34	—	—
	—	—	—	—	105.33	117.86	—	—
Mean	247.79	466.03	317.32	450.62	91.75	164.74	242.97	414.24

t values from above data

Source	Totals		Fungi		Actinomyces		Anaerobes	
	d.f.	t	d.f.	t	d.f.	t	d.f.	t
Cultivated versus sod	38	2.09*	38	3.30**	36	0.02	14	0.76
Cultivated, aggregated versus unaggregated	18	1.28	18	2.16*	16	0.74	22	0.28
Sod, aggregated versus unaggregated	18	0.78	18	2.45*	18	0.33	6	0.18

[1]All counts are averages of 12 plates x 10^4

*Significant. **Highly significant.

In Table 25 are recorded data on further studies of the microbial populations of the aggregated and unaggregated fractions. A series of t tests was conducted in the manner of Tables 21 and 23. The total population under sod is significantly greater than that found in cultivated soils. This indicates the usual changes brought about with the introduction of cultivation, namely, a decrease in bacterial numbers associated with a decrease in available carbon and nitrogen and a decrease in the state of aggregation.

Highly significant differences were also found when the fungal population under sod was compared with that in cultivated soils. A further analysis of the aggregated and unaggregated fraction populations resulted in significant differences in these for both sod and cultivated soils. The samples from cultivated soils were taken from the plots about 4 months after treatment when the soil had had a chance to return to a more nearly normal condition. The aggregated and unaggregated fractions did not differ in total populations, but there was a difference in their fungal populations.

Actinomyces counts did not yield significant differences between fractions. A study of anaerobes was undertaken in an attempt to gain information on interior conditions of the aggregate; no differences were found to exist between fractions. It should be pointed out that of the soil organisms studied, only those possessing a mycelial structure, that is, the fungi, were found in greater numbers in the aggregated fraction of the soil. With the exception of a short period after cultivation, all other organisms existed in greater average numbers outside the aggregate.

Reference should also be made to Table 13 where the state of aggregation has been recorded for field position. The F value for position was found to be significant, and statistical analysis of the bacterial data was conducted

in the same manner in an attempt to correlate the state of aggregation and bacterial numbers. The positional F value for fungal as well as bacterial numbers was not found to be significant. The higher state of aggregation at the center of the plots could not in this case be associated with higher bacterial counts. As noted above, this was probably the influence of the B horizon.

Runoff Data

Installation of runoff collector equipment was completed in the early fall of 1943; the arrangement has been described elsewhere. Precipitatation in the following months was scattered, weather conditions in general being dry. Those rains which fell were readily taken up by the soil. Warm weather for about 2 weeks late in January resulted in the loss of snow cover and the soil dried. Soil samples taken about this time contained 27 percent moisture and revealed good porous structure. The soil was in good condition to absorb rainfall.

A total of 0.98 inch of rain fell on January 26, 1943. Of this total, 0.60 inch, which fell in the first 20 minutes, perhaps contributed the greatest amount to runoff. Another rain on March 3, 1943, totaling 0.75 inch, also resulted in runoff. The data on these 2 rains are recorded in Table 26.

Even from this scant data there can be little question about the superior ability of straw mulch to retain rainfall during periods of short, heavy showers. The data are in agreement with results obtained by Lowdermilk (1930), Duley and Russel (1939), and others.

No runoff resulted from 2.1 inches of rainfall in early April, even though 2 inches fell in about 12 hours. It would seem that the stand of

wheat on the plots was sufficient at this time to overshadow the effect of surface cover.

Table 26. The relation of surface runoff to treatment.

Plot	Slope	Treatment	Runoff, 1943			
			Surface inches		Tons per acre	
			Jan. 26	March 3	Jan. 26	March 3
1	5.67	Plowed	0.162	0.012	18.65	1.37
2	6.25	Subtilled	0.001	0.000	0.12	0.00
5	6.43	Subtilled	0.000	0.000	0.00	0.00
6	6.05	Plowed	0.049	0.000	5.59	0.00
Total precipitation			0.98	0.75		
Percent loss, plowed			10.76	1.61		
Percent loss, subtilled			0.06	0.00		

Nitrate Accumulation

The plots were sampled for nitrates at seeding time in 1942 and 1943. The results are recorded in Table 27 with the analysis of variance and least significant differences.

The F value for years falls below the significant 5-percent level; however, there is little question concerning the differences in nitrate accumulation in the 2 years studied. The latter year was more nearly ideal for nitrate accumulation. Considering all plots and all treatments, the over-all accumulation of nitrate did not differ significantly with depth.

The F value for treatment (11.70) is highly significant. From the least significant difference it will be noted that plowing is superior to alternate plowing, which in turn is superior to subtilling, but that subtilling and alternate subtilling fall into the same class. It should also be noted that

Table 27. Average accumulation of nitrate in parts per million for different treatments at the designated depth and year.

Depth in inches	Treatment: Plowed 1942	Plowed 1943	Alternate plowed 1942	Alternate plowed 1943	Subtilled 1942	Subtilled 1943	Alternate subtilled 1942	Alternate subtilled 1943	Depth mean 1942	Depth mean 1943
0-3 "	53.24	91.70	50.80	76.95	37.31	59.24	33.99	55.22	43.84	70.78
3-6 "	48.57	85.94	42.95	75.10	32.55	59.38	26.89	64.34	37.74	71.19
6-12 "	36.69	56.47	27.37	42.24	35.72	38.52	31.78	40.05	32.89	44.32
Yearly mean	46.17	78.04	40.38	64.76	35.20	52.38	30.89	53.21	38.16	62.10
Treatment mean	62.11		52.57		43.79		42.05			

Table 28. Analysis of variance of data in Table 27.

Source of variance	Years	Depths	Treatment	Treatment x depth	Depth x year	Treatment x year
d.f.	1	2	3	6	2	3
Sum of squares	20,631.252	9,750.303	9,176.078	2,085.963	3,072.436	1,002.592
Variance	20,631.252	4,875.150	3,058.690	347.66	1,536.22	334.20
F[1]	13.42	3.17	11.70**	1.16	5.11**	1.11
Least significant difference			8.20		10.00	

[1]F values (mean square/plots within treatment, depth and year mean square)
**Highly significant.

subtillage has an immediate effect on nitrate accumulation, for results on alternate subtilled plots, 1943, indicate that the depression of nitrate accumulation by subtilling was as great when the plots were plowed the year previous as it was when the plots had been subtilled the previous season.

The over-all effect of treatment on depth is about the same for either treatment as shown by the non-significant F value, 1.16. In the 0 to 3 and 3 to 6-inch depths the order is: plowing greater than alternate plowing, greater than subsurface, and greater than alternate subsurface. From Table 27 it will be noted that accumulation in 1942 at the 3 to 6-inch depth was less than at the 0 to 3 or 6 to 12-inch depths under subtillage. The greater amount of moisture in August and September, 1942, has been pointed out before. This period was followed by dry, warm conditions in late September and early October. It would seem, then, that under subtillage, increased infiltration was accompanied by leaching from the zone of nitrate formation, in this case at or near the surface, to a lower depth. Nitrate accumulation then took place in a 0 to 3-inch section upon the resumption of more nearly ideal conditions. Krantz and Scarseth (1943) have also pointed out that nitrate tends to move to the surface with evaporation. The movement of moisture as shown in Figure 2 would seem to support such a thought. Subtilled plots began to dry after September 28.

The D value for 1943 was higher than for 1942. The result of more nearly optimum conditions for nitrate accumulation was a higher nitrate level in both plowed and subtilled plots. The differences due to treatment were more striking than in 1942. Continuous plowing gave a higher nitrate content than did any other treatment. There would seem to be some residual effect on nitrate accumulation due to treatment since the plots subtilled in 1942 and

plowed in 1943 show less accumulation of nitrates than do the continuous plowed plots.

There was a significant depth x year interaction. In 1942 the order of accumulation by depth was 0 to 3, 3 to 6 and 6 to 12, accumulation decreasing with depth. In 1943 the order was 3 to 6, 0 to 3, and 6 to 12, with accumulation of the first 2 depths at about the same level but that at 6 to 12-inch depth being significantly inferior. August and September of 1943 were drier than the same period in 1942, and the result was an accumulation in the surface 6 inches with no indication of leaching under any treatment.

The F value for plots within treatment, depth and year was highly significant when tested against duplicate determinations within plots. This serves to point out the variation in ability of plots to fix nitrates to the same extent under the same conditions. The mean square for plots within treatment, depth and year was used as the error term.

Yields of Grain and Straw

In Table 29 are recorded the height of plant at harvest time in inches and the yields of grain in bushels per acre. The grain was harvested by combine the last week of June in the summer of 1943. One 5-foot swath was cut lengthwise through the field; plot yields were sacked individually and weighed.

The averages for both height and yield are given with and without the values for plot 10. In preliminary studies on the total soil nitrogen in the different plots, plot 10 was found to have 0.126 percent nitrogen, whereas the other 11 plots averaged 0.134 percent; the lowest of these was 0.131 percent. It is possible that this low soil nitrogen of plot 10 has influ-

enced the yields.

It will be noted that either average for yield of grain on the plowed plots is greater than that for the subtilled plots. This would be expected in view of the low nitrate content of subtilled plots at seeding time and the conclusions reached by Sewell and Call (1925) concerning nitrate accumulation and yields in this area.

There seems to be a general relation between the height of plant and the yield of grain which would again infer a nitrate relation. Though the height of plant averages differ but little, they do reflect the same lack of cover that was found when plot cover was determined.

In connection with yields, the difficulty encountered in the control of volunteer should again be mentioned. The relation of volunteer to Hessian fly is not a desirable one from the standpoint of yields, and in bad "fly years" this lack of control could conceivably impair the crop. The appearance of the plots in March is shown in Plates V and VI. The difference in amounts of volunteer can be easily seen.

Table 29. Height of plant in inches and yield in bushels per acre - 1943.

	Height of plant in inches		Yield, bushels per acre	
	Plowed	Subtilled	Plowed	Subtilled
	37.9	36.5	38.54	30.39
	38.2	36.6	36.91	29.14
	37.5	38.0	35.40	36.67
	36.6	35.5	35.01	28.26
	35.0	37.3	27.33	32.29
	35.0	34.0	32.87	27.87
Mean	36.70	36.31	34.34	30.77
Mean less plot 10	37.04	36.31	35.75	30.77

EXPLANATION OF PLATE V

Surface of subtilled plot.

PLATE V

EXPLANATION OF PLATE VI

Surface of plowed plot.

PLATE VI

SUMMARY

A study of subtilled and plowed plots was undertaken in an attempt to answer certain questions concerning moisture relations, state of aggregation, nitrate accumulation, microbiological relationships, yields and other factors. The following observations have been made.

The presence of crop residues on the surface materially reduces runoff and increases infiltration. For extended drying periods the presence of mulches may tend to reduce soil moisture to a greater extent than in plowed unmulched plots.

Nitrate accumulation is markedly reduced by the use of surface mulches. Their use may also result in greater leaching of nitrate from the surface soil in wet periods. This lowered nitrate content is reflected in lower grain and straw yields.

The aggregated fraction of the soil contains more carbon and more nitrogen than does the unaggregated fraction. In soil that has been under cultivation for some time, however, the value of C/N is about the same for both fractions which indicates a similarity in the type of organic matter in the 2 fractions. When, on the other hand, these 2 fractions from sod or from cultivated soils which have received recent applications of straw are considered, a difference is found in their values of C/N which indicates different types of organic matter in the 2 fractions. The difference disappears in cultivated soils as decomposition progresses. These changes may be similar to those which take place when virgin sod goes into cultivation.

The studies on the state of aggregation have led to the conclusion that the surface cover may enhance or ~~may~~ reduce aggregation, depending on the

effect it exerts on soil moisture. On the soils studied, the state of aggregation increased with soil moisture. In subtilled plots the state of aggregation increased at a greater rate than it did in plowed plots. Under drying conditions in plowed plots it decreased at a slower rate than it did in subtilled plots. Aggregation in cultivated soils was found to be more erratic in its changes than aggregation under sod. The aggregates from sod were also found to hold more water than those from plowing. These characteristics are probably related to a labile carbon fraction found in sod aggregates but not present in aggregates from long-time cultivated soils.

Bacterial analysis of the aggregated and unaggregated fractions as they occurred under field conditions brought to light no continuous significant differences in total bacterial numbers, though numbers in the unaggregated fraction usually averaged higher than those in the aggregated fraction. Shortly after the time of treatment the aggregated fraction on all plots contained a significantly higher number of total organisms than did the unaggregated fraction, while 2 months later the condition was reversed. This has been taken to mean that a temporary type of aggregate was present after treatment, brought about by decomposing organic matter. Associated with this were high counts of total organisms. When the aggregate disappeared, as shown by a return to normal values of the carbon in the aggregated fraction, the bacterial population was released to the unaggregated fraction. Numbers of actinomyces and anaerobes were not found to differ between fractions.

Fungal counts were depressed under subtilled plots at the time of treatment and remained the same or slightly increased under plowed plots. Two months after treatment they had increased. In this way they followed the same trend as the state of aggregation.

Further studies on sod and cultivated soils showed significantly higher total counts and fungal counts under eod. In these caees also there wae a eignificantly higher fungal count in the aggregated fraction than in the unaggregated fraction. It ie possible that fungi can affect the etate of aggregation due to the nature of the mycelia. It ie highly doubtful that true bacteria exert any appreciable long-time effect on the aggregated fraction. The amounts of carbon and nitrogen found in the unaggregated fraction of soils are sufficient to sustain ite population. The presence or absence of organisms ie influenced by availability of food and not by quantity.

Becauee of greater difficulty encountered in control of volunteer, the need of better implements for cultivation, the lack of nitrate accumulation and its effect on yields, subsurface tillage cannot be recommended for this area at this time.

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